A Water Demand Analysis for the Massachusetts Institute of Technology

by

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B.A., *cum laude*, Whitman College (1982)

Submitted to the Department of Urban Studies and Planning in partial fulfillment of the requirements for the degree of

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Abstract

A statistical analysis of water consumption at the Massachusetts Institute of Technology between FY80 and FY91 provides measures that help identify targets for water conservation at the institutional level. First, information from a variety of institutional sources is brought together to provide matter for study. This work proved the most time-consuming, but provided the basis for succeeding analyses. From these data came a new metric, gallons per usable square foot per time period, that allows conservation officials to assess water consumption by building type. Three types of buildings are defined for MIT — offices, dormitories, and combined office and laboratory spaces. Each possesses a characteristic water consumption rate that may be used to identify places where water usage is excessive. Two simple pooled time series multivariate models relate total water use and water consumption rates to factors such as space usage, equipment usage, weather, and time. These models indicate that useable square feet provide a good estimator for total water consumption in a building, and that both useable square feet and equipment usage help explain water consumption rates. Finally, suggestions for improving information management are offered so that facilities managers may sustain routine utilities conservation programs.

Thesis Supervisor: Lyna Wiggins
Title: Associate Professor

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Like all theses, this work could not have been completed without the help of many people. In this case, I owe much to staff members at MIT. In Physical Plant, Michael Taub and Raul Varela granted free access to much of the critical data required for the study – water consumption and electrical consumption figures and costs. They also showed consistent interest in the progress of my work. In the Office of Facilities Management Systems, John Bidwell gave access to vital information about space usage at MIT. In the Planning Office, Michael Owu supplied information about building ages and space renovations for the campus over the years of study.

The very idea of doing a water conservation study at MIT would not have struck had I not worked on a project that explored a geographic information system for MIT over the spring and summer of 1991. I am grateful to Peter Roden, Jon Rochlis, and Tim McGovern for supporting that work at that time. Ed Moriarty, of the Department of Electrical Engineering and Computer Science, likewise provided his usual insightful, enthusiastic, and humorous perspective on my efforts over that period.

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Also, thanks to the creator of Pearson's Coffee Nips, which saw me through many an evening this spring.

Finally, I need to express my gratitude to my family for its long-standing commitment to the causes of resource conservation and public service. Ralstons and Speers have worked at least since the 1930s to teach people a due regard for the bounty of our earth. This project marks my commitment to that legacy, and the beginning of my contribution to that heritage. In taking this path, I know that the examples provided by my grandfather and my father will serve both to guide and to inspire. I cannot thank them enough.

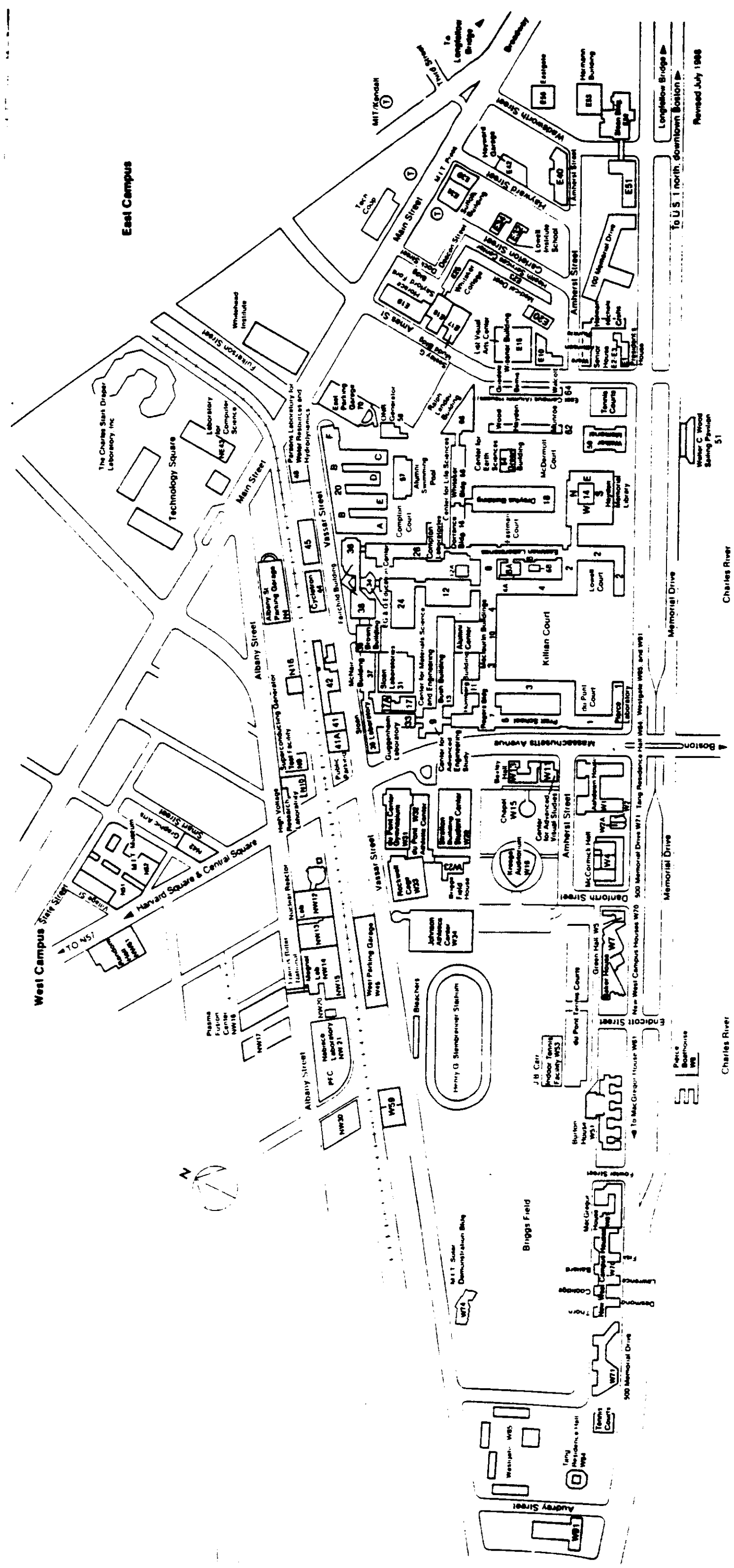

Figure 0-1: **The Campus of the Massachusetts Institute of Technology**

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Chapter 1

Introduction

Early in the 1980's, Federal enforcement of the United States' Clean Water Act of 1970 forced the Commonwealth of Massachusetts to begin cleaning up Boston Harbor. The state was required both to renovate its primary sewage treatment facilities and to construct secondary sewage treatment facilities. In doing so, the Commonwealth had to proceed almost wholly without benefit of Federal aid. Furthermore, it had to act decisively. Both Federal and state judicial authorities threatened either to forbid sewer hook-ups — a serious blow to construction in the state — or to put the Metropolitan District Commission, the agency then responsible for managing the sewer system in eastern Massachusetts, in receivership if progress proved slow. In time, the state created a new administrative body, the Massachusetts Water Resources Authority (MWRA), to oversee the project.

While the state legislature commissioned the MWRA to clean up the Harbor, it also mandated that the agency "safeguard an adequate and pure supply of water for future generations." [1] And the state specifically identified water conservation as one means to that end.

If MWRA officials ever considered appropriating more water from western Massachusetts to fulfill the law in this area, such plans quickly became impractical. Constructing new sewage treatment facilities to safeguard harbor waters led directly to noticeably higher water bills for rate-payers. Politically and economically, it became impossible to raise rates yet more to build the reservoirs, aqueducts, and pipelines needed for augmenting water supplies to the Boston metropolitan area. Systematic water conservation had to be implemented for the MWRA to fulfill this part of its commission.

MWRA customers, for their part, found ever-rising water and sewer costs themselves a powerful impetus to water conservation. Institutional as well as residential customers were affected. Hospitals, manufacturers, and universities, among other institutions, all relied on cheap water to help keep their operating expenses low. With costs no longer low, with no end of rate increases in sight, and with their volume of usage high, institutions had a special incentive to conserve as effectively as they could. The Massachusetts Institute of Technology (MIT), as the largest consumer of water in Cambridge, likewise had — and today has — a strong interest in reducing its overall usage.

In tackling campus water conservation, MIT officials face an array of problems, not the least of them financial. A controversy over the Institute's methods of calculating overhead charges for research together with a history of rapidly increasing tuition charges prevent MIT management from using either of these instruments exclusively to absorb its added water expenses. Yet conservation requires an investment in infrastructure. Leaking pipes have to be found and fixed. Older style toilets, shower heads, and faucets need to be disposed of; new fixtures need to replace them. With campus facilities of 9 million gross square feet, Institute managers face the challenge of paying for this investment out of the savings made from the investment.

Two problems in particular derive from a shortage of readily available information, however, that inhibit good conservation planning and practice. First, to comply with MWRA regulations that now prohibit once-through cooling of equipment, MIT administrators have to find where lasers are used around campus, then capture and re-use the water that cools this equipment. Second, they have to find out where water is being wasted.

The first problem may be dispatched with relative ease. Equipment purchases such as those for lasers are logged with the MIT Property Office, which records both the date of purchase and the location of the equipment. Assuming that these items are accurate, it is possible to learn how many lasers remain on campus and where they are concentrated. This information may be queried and printed; the locations audited; equipment cooling practices targeted and changed over time with effort, yielding a big payoff in water savings and large cost savings to the Institute.

The second problem proves somewhat more difficult. MIT officials must identify where water is wasted before they can target conservation efforts. Yet Institute facilities embrace an enormous area comprising a diversity of spaces. Uncovering wasteful water use requires detailed knowledge of space usage. This understanding usually comes from auditing that is more thorough and particular than the sort required for routine operations. So campus administrators need to learn what facilities usage is like at a greater level of detail than normal.

Consequently, MIT staff also face the problem of sustaining their conservation program over time. Even if a one time audit of the campus reaps immediate water savings, continuous Institute-wide conservation efforts require that this detailed level of understanding somehow be maintained. They need information that helps to identify areas of greater than average water usage, indicates possible causes of extraordinary usage, and informs priorities for reducing usage around campus.

Both of these problems are complicated by limited information about water usage on the main section of campus, where half of all the water used by the school is consumed. This area includes classroom, auditorium, office, library, laboratory, and residential spaces, as well as athletic facilities and dining halls, so no one type of facility predominates. Few individual buildings there have meters. Normally, only the few connections to the Cambridge water system are monitored. Staff know much about aggregate use on the main campus, but comparatively little about how water usage varies within that space. Having information in such an amorphous form prevents staff conservation managers from differentiating water usages, identifying their targets, and setting priorities for conservation.

In the absence of plans to expand metering dramatically or to audit water usage extensively, analytic methods and better information management offer tools for getting out of this bind. Descriptive statistics together with time series techniques may identify patterns that lie beneath the surface of aggregate usage figures. Correlations between water usage and other variables and regression analysis may identify good predictors for water usage that may be more abundantly available than water usage statistics themselves. Finally, bringing together data from disparate sources may help to put water consumption data in a context that helps to inform the focus of conservation efforts.

Statistical tests, however, like all tools, do no good if they work to no purpose — or if the purposes to which they are put remain ill-defined. In this case, at least two specific questions present themselves for consideration. First, what factors contribute to overall water consumption on campus? Staff from MIT's Physical Plant Department need to know about these factors. Knowing more about these factors may bring forward good predictors for water consumption and good targets for water conservation, especially on the main part of campus. Two hypotheses suggest themselves. One argues that water use is similar to electrical use, for both imply the presence of people, of work and living space, and of equipment. If a strong relationship exists between these two variables, then readings from electrical meters in the absence of water meters may provide a rough guide to water consumption and water savings. Another hypothesis, already assumed by Physical Plant staff, argues for a strong relationship between water consumption and lasers. The extent to which lasers are a good predictor for water usage still needs to be articulated.

Three perspectives seemed appropriate for gaining some insight into this question — one that looked at water usage and related variables for the entire campus; one that looked at those parameters for all sections of campus; and one that examined them at the building level for those buildings about which relevant data were available. Following established patterns of investigation by studying each data set with the simplest tools — averages, standard deviations — and proceeding as necessary to more specialized techniques provided the general method for resolving more and more particular questions as they arose in the course of this work. In particular, time series analysis and multivariate regression promised to help articulate the relationship between water consumption and other explanatory variables.

The second question is, if water patterns *away from* the main campus can be isolated that resemble water patterns *on* the main campus, is it possible to develop an index that helps to guage water use in the center of the Institute? The Main Campus is the largest water user, has diverse useable space, and few meters to measure its demand. Comparing space usage between different parts of campus seemed likely to inform approaches to campus-wide water conservation. In addition, developing a figure for average water consumption per square foot of useable space seemed likely to provide a standard for comparing water usage across campus.

In succeeding chapters, this thesis will go into each of these areas in greater depth. Chapter 2 provides more background on the history of water usage in Massachusetts, on the role played more recently by the MWRA in promoting water conservation, and on MIT — its culture, its history, and its problems in conserving basic utility resources. It then discusses these problems at somewhat greater length in an attempt to explain why they deserved several months of concentrated study. Chapter 3 states the research problem in slightly greater detail than is possible here. Chapter 4 relates how appropriate data were identified; how data were collected; how their accuracy was measured; and how they were organized into their final form before analysis began. Chapter 5 details the descriptive statistics and time series analysis that were applied to the appropriate data sets and presents the results in a series of tables. Chapter 6 details the procedures used to develop two multivariate statistical models for campus-wide water consumption and assesses the models themselves. Finally, Chapter 7 draws some conclusions about water usage at MIT from these results, assesses this analytical exercise, recommends next steps in the analysis, and suggests next steps in actual MIT operations to build upon this work.

Chapter 2

Background

Conservation programs, like all planning efforts, operate in a complicated web of conflicting interests, traditions, and values. These elements figure at least as much as the financial and technical resources that are available for use at any given time, even though they are given relatively little attention. Perhaps they operate more subtly; perhaps they are so obvious that they draw little comment. Whatever the reason for paying so little attention to these factors, conservation programs are organized and administered by people who work within and between established institutions. Both individuals and institutions have interests; interests help establish priorities; and priorities, whether they are adopted after some period of rigorous reflection or simply out of habit, drive action.

A thoughtful conservation plan, therefore, and the analysis carried out to support it, has at least to consider these forces and to come to terms with some of them if it is to effect change. An effective plan has to work at the causes of the problem at hand. If it fails at this, it cannot succeed; efforts on behalf of such a plan will by definition be misguided, hence ineffective.

This chapter, therefore, attempts to put this water demand analysis in some context. Two histories have to be related. One deals with the relevant political traditions in Massachusetts by sketching the history of water usage in the state, outlining the impact that the environmental movement has had on this history, and relating relevant details about efforts of the Massachusetts Water Resources Authority to enforce water conservation in its service area. Another story deals with the Massachusetts Institute of Technology (MIT) — its culture, its tradition of resource usage, and the problems that it faces in implementing new conservation efforts.

2.1 Water Usage in Massachusetts

In Eastern Massachusetts, the 340-year history of the water system is almost exclusively one of regularly increasing demand due to a growing urban population; degrading water sources; and the appropriation of clean water from around the state for residents of Boston and its suburbs. As early as 1652, Boston residents had grown so numerous that a spring in the Boston Common no longer satisfied their need. A water works company was created to build new cisterns and conduits to transport water from elsewhere in the vicinity to the center of the city [1]. By 1795, Bostonians reached out to Jamaica Pond for water. In the Nineteenth Century, Boston's water system expanded further west, diverting water from Lake Cochituate, near Natick, in 1848; from the Sudbury River in 1872; then from the Wachusett Reservoir in 1895. Finally, as per capita water usage grew in the early part of the Twentieth Century, two more major water sources were developed — the Ware River and the Quabbin Reservoir [14, p. 7].

In part, this history was one consequence of the climate and terrain of the region. In contrast to the Western United States, New England has always enjoyed ample rainfall and plentiful drainage. Water here was never a scarce resource over which individuals or communities would fight. One proof of this difference lies in the legal doctrines that New England states adopted concerning water usage. In the East, the Riparian Doctrine granted land owners practically complete control of the streams that flowed by their property. In the West, water rights were regulated much more strictly, and were the source of considerable contention between interests and individuals [3]. Another piece of evidence lies in New England's economic history. It was the ready availability of swift running water that made possible the factories and mills that first created, then sustained Massachusetts' economic power during the Nineteenth Century.

By the 1970s, however, conditions that nourished this tradition of an expanding water system had changed. The social concern that inspired public movements in the 1960s heightened people's awareness of threats to their communities, including threats to local natural resources like open space and water. Supported in part by a growing environmental movement [9, p. 1], citizens demanded, and got, greater community participation in public decisions. The consequence in issues of public construction — such as those surrounding roads, bridges, highways, power plants, and water works — was the presence of a group agenda that worked against large-scale development that threatened existing habitats. As the Massachusetts Water Resources Authority itself notes,

> In the past, substantial alteration of the natural and man-made environment in one location for the "greater good" of the urban dwellers was considered more than reasonable. Now, a new consciousness of the long-term destruction of the environment call the traditional trade-offs into question [14, p. 7].

In other words, environmentalists, as participants and leaders of citizen movements, challenged the premises that traditional water supply planners took as given. Their challenge acted as a brake on large-scale infrastructure projects, including those concerned with water delivery.

At about the same time, demand for water in the Boston metropolitan area again outran its supply. Just after the Sudbury Reservoir was taken off-line in 1967, Eastern Masschusetts began operating over its safe yield of 300 million gallons a day (MGD); these operations became normal for a period that was to last two decades [14, p. 22]. As the local population grew, as conveniences such as washing machines and dishwashers proliferated, as per capita water use increased, Boston water supply planners again looked westward for new sources, eyeing the Connecticut River, west of the Quabbin.

In Massachusetts, environmentalists challenged proposals to extend Boston's water supply to the Connecticut River – and to other rivers, such as the Merrimack – on both technical and procedural grounds, invoking the environmental impact review process to counter pressures for development [14, page 7]. In taking this position, environmentalists argued that much water was wasted, either through poor management of demand; poor maintenance of pipes and aqueducts; or inefficient use of water by residential, commercial, and industrial customers. Indeed, as late as 1980, Massachusetts water management had failed to change water pricing structures so as to discourage water consumption instead of rewarding it [17]. Environmentalists urged more efficient use of existing resources in place of increased investment in infrastructure.

By continuous exercise of the legal and political instruments at their disposal, environmentalists managed to stymie proposed development thoughout the 1970s and into the mid-1980s. As population grew in the Boston metropolitan region and as water quality declined due to the overextension of available resources, pressure increased to break the stalemate. Other forces worked, however, to help conservation become more than an ideological issue. Through the 1980s, as money for public works grew more scarce, conservation came to be seen as an economical and practical tool for satisfying demand. As noted in 1984 by Richards, *et al*,

> . . . there is now increasing recognition that full time water conservation programs may be economically attractive since capital expenditures may be avoided or postponed if water demands, and hence design flow rates, can be significantly reduced [23, p. 1-1].

In Massachusetts, economic arguments proved compelling despite a boom in the regional economy. By 1985, a court ordered clean up of Boston Harbor forced planners to prepare for dramatic increases in water rates to pay for decades of neglect of metropolitan sewer systems. Required to invest billions of dollars in primary and secondary sewage treatment facilities to meet the provisions of the Clean Water Act of 1970, yet ineligible for Federal money to assist in this effort, Massachusetts water planners found themselves bereft of the means to pay for the reservoirs, aqueducts, and pipes needed to expand their water supply.

With the creation of the Massachusetts Water Resources Authority (MWRA) in 1984, conservation efforts took on more programmatic form in Massachusetts. The MWRA Enabling Act stipulated water conservation as one of the Authority's primary purposes. Related legislation — the Interbasin Transfer Act, the Water Management Act, the Massachusetts Environmental Protection Act — required extensive impact assessment, eliminating the possibility of quickly appropriating existing water sources for Boston's use, and requiring the exhaustion of every alternative to this kind of appropriation before permitting it [14, p. 18]. Considering these legal restrictions together with the cost-effectiveness of water conservation compared to capital investment, the MWRA faced a situation in which conservation became almost the only option that allowed them to satisfy their duty to Massachusetts rate payers.

Among the steps that the MWRA took to encourage more efficient use of Massachusetts water, two proved particularly important to institutions. First, partly out of necessity, partly as a matter of policy, the MWRA raised the prices it charged local water authorities, particularly for sewer services. At MIT, this change in practice resulted in more than a 100 percent increase in the real cost of sewer services over a span of ten years (before adjusting for sewer rebates, using base year for CPI of 1982-84 = 100). (See Figure 2.1) This rate of increase, and the likelihood of its continuation, forced MIT staff and their peers at other institutions to seek continuous reduction in water usage just to keep their water budget increasing with inflation.

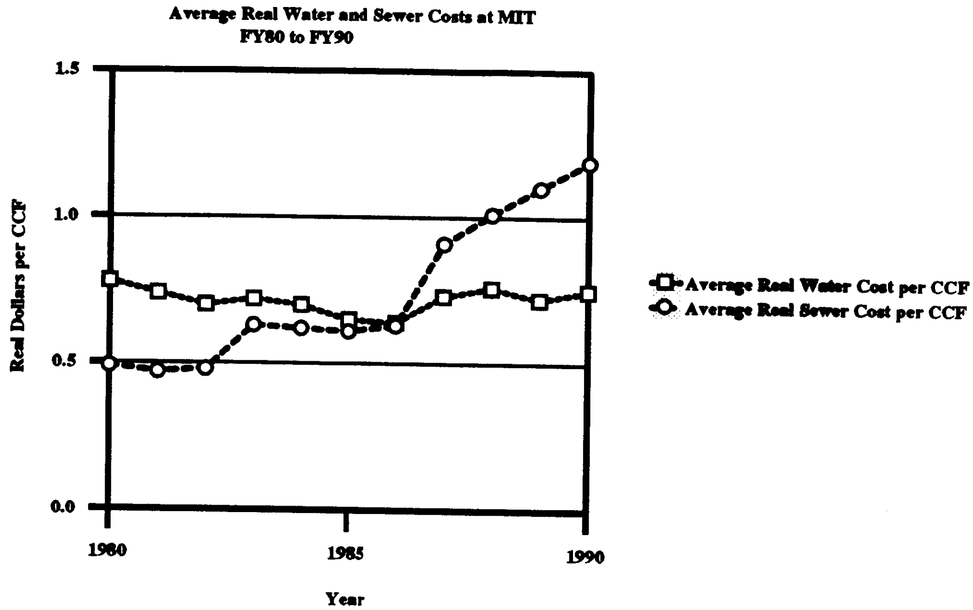

Figure 2-1: **Real Water and Sewer Costs Per CCF for MIT, FY80 to FY90**

A second change in policy reinforced this impetus to conservation. In order to discourage waste, the MWRA prohibited the discharge of cooling water to MWRA sewers. MWRA regulations read:

> 10.023: Specific Prohibitions
> The following discharges are specifically prohibited:
>
> . . . (2) Non-contact Cooling Water and non-contact industrial process waters or uncontaminated Contact Cooling Water and uncontaminated industrial process water.

More recently, the MWRA has proposed the elimination of once-through cooling, as well as changes to heating, ventilation, and air conditioning (HVAC) operations that could yield additional savings in water use. Once-through cooling systems waste water on a grand scale by using fresh water once only to cool equipment and machinery. Except for being warmed, the water often is unchanged by this process; it could easily be recycled, and therefore used more economically. At MIT, lasers enjoy widespread use and operate practically without regulation. MIT Physical Plant staff suspect that once-through cooling is routine. Thus, these proposed regulations have the potential to affect many labs' regular practices. The HVAC regulations may likewise affect Physical Plant operations dramatically.

2.2 MIT and Resource Conservation

The Massachusetts Institute of Technology is an internationally recognized school of research in science and engineering. It attracts some of the most intellectually able students and researchers in the world, bringing them together to focus on advanced work in all branches of science and technology. This work takes place in a physical plant that now exceeds nine million square feet of space on 145 acres of land that stretches east from Cambridgeport along the Charles River in Cambridge, Massachusetts. [19, p. 30] (See Figure 2.2)

The campus plant itself comprises a diversity of facilities in about 140 buildings that includes residential, classroom, office, laboratory, and public assembly spaces. Buildings range in age from several years to almost eight decades. Much of the campus space is of relatively recent construction, a result of post-war campus expansion. Between 1962 and 1981, MIT doubled in size, growing from four to eight million gross square feet; MIT added another one million gross square feet during the 1980s [2]. The main group of buildings, however, taking in approximately one million gross square feet, dates back to 1916, when MIT moved to Cambridge from Boston.

In its mix of building ages and facilities usage, MIT resembles other universities, hospitals, and research facilities. From another perspective, however, MIT looks rather more like a small city with its own residential, manufacturing, commercial, and office spaces. Most of its working population of approximately 17,000 people commute to the campus during the day and leaves at night; a smaller segment of that

Figure 2-2: **Location of the MIT Campus**

community lives in the dorms and the immediate vicinity of campus takes advantage of the social, cultural, and recreational activities available there. Looking at MIT this way helps to put the challenge of water conservation there in a somewhat more realistic perspective.

While the MIT campus is relatively compact, its utilities use is intense. For example, MIT is far and away the biggest consumer of water in Cambridge. In FY91, extending from July 1990 to June 1991, its annual usage totaled over 600,000 hundred cubic feet (CCF) of water — over 450 million gallons. In fact, this total represented a slight decline in water usage from past years. For fiscal year 1989, the City of Cambridge recorded usage of 560 million gallons of water at MIT. Yet this figure loses some of its meaning in isolation from the larger context of water use in Cambridge. That year, MIT's total water usage was greater than that of the second biggest user of water in Cambridge, Harvard University, by approximately 180 million gallons a year, a difference of almost 50% [5, p. IV-106]. This difference exists despite Harvard's greater size – about 350 buildings and a campus population of 22,000 [4, p. 39]. To make this figure even more staggering, MIT's water usage that year was almost 40% more than *twice* the usage credited to Cambridge Electric. If Harvard and Cambridge Electric were excluded from consideration, MIT's appetite for water would have surpassed the combined total of the next thirteen of the City's top water consumers, a group that includes one large hospital, two confectionary manufacturers, two biotechnology firms, Polaroid, two hotels, and several large office buildings [5, p. IV-106].

One ready explanation for this level of consumption lies in the kind of research that goes on at MIT. Researchers undertake advanced work in technology. Sometimes this involves running what amounts to small scale industrial processes that rely heavily on inputs like electricity and water. Other contributing factors round out this explanation, however. Of fundamental importance is the fact that resource conservation at MIT is a secondary objective. That is, electricity and water at MIT involve

> . . . activities the organization must carry out, products it must produce, and services it must provide so primary objectives can be pursued unbridled. These activities provide direct support for the input, transformation, and output functions [4, p. 26].

These facts together bring with them a long train of consequences for how utilities are managed at MIT. The overall effect is to create incentives that keep Physical Plant operations in the background, separate from the faculty and students who use utilities so greedily. The primacy of research goes unchallenged because it is the lifeblood of the Institute, part of its proud tradition and the means to sustaining that tradition. (To cite one measure of its importance, research revenues accounted for 76% of the Institute's operating budget in FY70, 71% of the budget in FY80, and 69% of the budget in FY90. [19, p. 41] Thus, MIT has depended heavily on research money for quite a long time just to keep operating. And since overhead provides for operating expenses, MIT has, until recently, had little incentive to reduce its operating costs.) Physical Plant serves the Institute. As a matter of tradition [4, p. 267] and policy [4, p. 297], staff are encouraged to operate on the periphery of MIT's laboratories instead of engaging faculty and students about how water, for example, might better be used.

The task of conservation is further complicated by the Institute's relations with its neighbors in Cambridge. Drastic reductions in resource usage can have enormous impacts on the local community. In another case involving plans to construct a power cogeneration plant, MIT deliberately maintained its commitment to purchase power from Cambridge Electric "to avoid changing the electric rate structure of the Cambridge area" [4, p. 308]. The same problem holds with water conservation. The City of Cambridge relies on MIT water consumption to help pay its operating expenses. If MIT reduces its usage dramatically, Cambridge may have to raise its rates even more than it must just to respond to MWRA rate hikes. These increases have the effect of further limiting the community's disposable income and altering the local economy.

All these conditions impose constraints on the rate and kind of water conservation that MIT may pursue. Thus, MIT presents a considerable challenge to those who have responsibility for managing its facilities. First, its Physical Plant staff cannot indulge a radical water conservation plan even if it had the money to do so. Second, not only do they have to deal with buildings of varied age and usage, they have to deal with utilities usage on a scale that outstrips most comparable institutions. Third, they have to perform this work in a way that guarantees acceptable service levels without intruding on the work that MIT's scientists and engineers pursue every day. Fourth, they have to be careful to coordinate changes in utilities consumption with the City of Cambridge.

2.3 Forming the Problem Statement

Before dealing with any of those problems, however, Physical Plant must understand where water is used, where water can be saved, and how much can be saved in a given period of time. As Cebon notes, one consequence of the distance that separates the Physical Plant Department from the labs and offices around campus is that Physical Plant "lacks contextual information" [4, p. 296]. This kind of information may contribute importantly to whatever water conservation plan emerges from the Physical Plant department.

That staff lack contextual information is a far cry from saying that conservation efforts go forward in ignorance. The staff at Physical Plant have enough meters to identify where water is consumed outside the main campus. They work enough with existing facilities to make educated guesses about where they can make sizable savings in water consumption on main campus. They also know enough about the kinds of uses to which buildings are put to have a good general sense of where and how to target savings.

Nevertheless, water usage patterns for the central part of campus remain a mystery to Physical Plant staff, as only eight water meters there record usage for the entire section of campus. Therefore, Physical Plant staff have comparatively little idea of how water usage changes on a building by building basis for an area that sees the greatest amount of traffic on campus. In addition, no thorough analysis of current water usage with existing data has been performed to confirm or refine their understanding of water usage around campus, acting as another limit to implementing conservation. Finally, while Physical Plant has worked hard with MIT Information Systems to plan a data base that will help them to manage their utilities records and cost accounting better, little work has gone toward combining this billing information with space usage information that is available from MIT's Office of Facilities Management Systems or with equipment location information from MIT's Property Office. Thus, while the Department of Physical Plant has begun to develop information systems that will enable it better to manage its utilities, it has yet to use available information that will improve water usage monitoring so as to target sites on campus for resource conservation and to adjust quickly and knowledgeably to changes in water usage around campus.

This thesis proposes to explore these problems and to lay out one approach that might help remedy this lack of contextual information. In doing so, I assume that this lack of information, together with other factors, inhibits Physical Plant from developing conservation plans that might save both water and money. I also assume that Physical Plant's tendency to prefer engineering solutions to other approaches will remain substantially unchanged over time. Hence the emphasis in this study on information solutions instead of organizational solutions. The concern of this thesis is to explore how existing, readily available information about MIT may be leveraged to enhance Physical Plant utilities planning. It proposes to do so by applying simple, familiar statistical techniques to the data that Physical Plant has available to it and to data from other offices in MIT that may help better to explain utilities use at MIT. In the end, this work explores how analytical techniques may be used to improve the focus and effectiveness of a sustainable conservation management plan at MIT.

This approach runs against the recommendations of some findings from previous work in water conservation. Indeed, the idea that conservation is something good in itself receives a direct challenge, although conservation on the basis of an economic argument generally receives support. [26] Other studies conclude that technological solutions, while frequently the option of first resort, may often be more expensive than institutional approaches that change people's behavior.

> . . . our society is, and has long been, a technologically oriented one. We have been successful in technological innovation and we have to to look first for the "technological fix" when we confront a new problem. At the same time, we are institutionally backward. We shrink from institutional change, except as a last resort [15, p. 655].

While other studies recognize the value of engineering and technology to the process of conserving water, they also stress the importance of other elements in the planning process that support conservation, such as public education, in order to insure effective long-term savings [8, p. 140]. Maier, *et al*, go so far as to maintain that water conservation must *begin* with public information programs that accompany installation of water saving devices [16, p. 676].

Even admitting these limits to a modeling exercise, the very usefulness of modeling for forecasting purposes comes in for questioning. Osborn, *et al*, reviewing the accuracy of water demand forecasts in the 1960s, found them often inaccurate, and frequently accurate only by virtue of offsetting errors in the model components [21, p. 108].

Even here, however, Osborn recognizes the potential value of models as management tools — something that can "organize our understanding of factors that influence water use [21, p. 108]." He also recognizes the value of model-making for short-term forecasting [21, p. 109]. Likewise, Whipple recognizes that conservation has economic value when savings warrant the investment required to realize those savings — although he regards most water savings as "justified largely by the saving of energy rather than water [26, p. 819]." And Lord states that " . . . technology cannot be developed or applied except within the framework of social institutions, and . . . institutions must work through technology to make a difference in the state of the nonhuman world [15, p. 656]." This implies again the need for conservation plans that coordinate technology — in this case, model-making — and institutional action.

That such dissenting statements even appear implies the routine use — some would suggest the overly routine use — of modeling to forecast water usage and to prepare for growing water demand. Domokos, *et al*, doubtless publicize their analysis of problems in forecasting water usage in order to guide planners and engineers away from common pitfalls with demand modeling [6]. The standard tools available to statisticians — time series analysis and regression — apply to these situations and have been put to use in a variety of contexts. Kim and McCuen apply multiple correlation analysis and principal components analysis to understand commercial water use [12]. Hanke and de Maré perform a pooled, time series cross sectional study of residential water use in a town in Sweden [10]. Yamauchi and Huang apply both multiplicative and additive time series models and stepwise regression methods to water consumption data to understand municipal water usage [27]. Lee and Warren use a multiple regression model to help evaluate the effectiveness of water conservation efforts [13].

All this published work probably only hints at the scale of actual modeling done on water usage. That so much statistical work goes on cannot itself justify applying statistics to this particular situation. The reasons given for these efforts, however, do help to explain why such an effort may be valuable on the campus scale.

At first, applying statistical methods to institutional water use may seem to indulge overkill. Indeed, statistics developed originally to help government officials and businessmen understand change over large territories — cities, counties, nations. Most applications of statistics continue in this mold; water usage is no exception. Nevertheless, businesses and governments at all levels use at least some form of forecasting and analysis to understand where they are succeeding and where they are failing. Corporations rely on projections to plan business strategy. Consultants are retained by all manner of institutions to apply statistical methods to the problems that those institutions face. In fact, some studies in modeling water use do apply these techniques to areas not much larger in acreage than MIT, and with decidedly less diverse facilities [20]. Applying these tools to such a local level for purposes of management thus represents only a small departure from the prevailing tradition. Therefore while approaches from larger scale studies must be adapted or translated to this particular application, they needn't be twisted to fit this situation.

Furthermore, although the literature indicates — as one would expect — that these tools should be used knowledgeably, with full appreciation for their limitations, they never argue that the tools should be abandoned. As noted, even though Osborn finds most of the important water use forecasts from the past sufficiently inaccurate to discount their value for long-term planning, he still considers forecasting valuable "if the forecasting exercise is seen as a flexible water management tool rather than a definitive investment planning tool [21, p. 109]." If modeling is used in this way, "forecasting can, as Ascher (1978) proposes, allow us to posit alternative scenarios for future resource use, and allows us to select and pursue a particular scenario [21, p. 108]."

This approach to modeling squares nicely with the needs of Physical Plant staff, who intuitively understand general water usage patterns on campus for the past and present, know where residential use may be reduced, and have a good idea about how water usage may be reduced there. At the same time, there are large areas of campus, encompassing residential, office, laboratory, and classroom use, that remain largely a mystery to them. This lack of knowledge follows from the smallness of their staff, the scale of the Institute, and their distance from the departments and labs where utilities usage takes place. They have some means to increasing their understanding of these places, however, since they themselves have utilities usage data, while other offices have supplementary information about the Institute. By bringing this information together and applying basic statistical procedures to the resultant collection, they can take steps to overcome the current gap in contextual information that impedes more systematic water conservation management on campus.

Of course, this effort will not of itself remedy the institutional problems that get in the way of implementing water conservation on campus. MIT staff have to work together daily to create a new reality of resource conservation. It can, however, provide an example of the kind of analysis that is possible when data from disparate sources are brought together to help form a picture of how a resource is being used, what elements contribute most to its use, and how those elements may themselves be managed to bring about economical use of those resources.

Chapter 3

Problem Statement

In order to improve water conservation planning, MIT staff, university officials like them, and adminstrators who are responsible for facilities management need to understand more clearly what factors contribute to institutional water consumption. That is, they need not only to know *what* causes water consumption, they need to appreciate *how much* each factor contibutes to total consumption. Conservation programs can and do function without this information, of course, but they will be less efficient, less effective, and more difficult to sustain institutionally than they might otherwise be were knowledge of resource usage more detailed.

In MIT's case, conservation officers need to confirm their hypothesis that equipment usage contributes significantly to overall water consumption. The Institute will profit, too, by learning the extent to which lasers contribute to overall water usage. Should statistical tests fail to reject the hypothesis that lasers have little bearing on water consumption, this theory itself will need to be reconsidered. The question of how exactly equipment contributes to water consumption at research universities deserves serious attention.

In addition, conservation program administrators require a simple tool that allows them to estimate normal water usage by the kind of space usage that prevails in a particular building. Since dormitory usage is easily identifiable, a value for this kind of space may already be known. Nevertheless, conservation managers have found it difficult to calculate the same figure for office space and laboratory space at MIT because such spaces are frequently mixed together on campus. A simple definition of laboratory space needs to be created, and average usage for laboratory and office space calculated to complement the figure for dorm usage.

Finally, Physical Plant staff need to know what available information will help them manage utility conservation programs better, and what tools and procedures they need to consider when incorporating that information into their own work. Therefore, this thesis will present a brief consideration of the information used for this study and offer some suggestions for improving this area of data management.

To address these problems, I will first develop and present descriptive statistics for water usage for the entire campus, then perform a time series analysis for campus-wide water usage at MIT for FY80 to FY91. Furthermore, time series analysis will be performed for the different sectors of campus — Main Campus, East Campus, West Campus, North Campus, and Northwest Campus — to discern any geographic variation in the trend of water consumption at the campus. These analyses will supplement and provide context for the multivariate model.

In order to understand water consumption in detail, this part of the analysis will concentrate on semi-annual usage rather than annual usage. Using semi-annual readings may seem at first to constitute too large a level of aggregation. It is the lowest level available for the site of study, however. It compares favorably, too, with published studies that used even fewer readings of semi-annual data to establish a plausible model for an entire city [10].

In response to the need for a measure of water consumption by space usage, figures for average water usage per useable square foot will be developed. These numbers will be calculated for the entire campus and for different areas on campus to permit comparison of water usage across campus. Gallons of water consumed per useable square foot will also be calculated for individual buildings where possible so as to identify buildings with comparable water use. These figures may help to identify spaces on campus with similar consumption patterns, allowing reasonably accurate forecasting of water consumption by type of building space. At the same time, these figures provide a consistently measureable standard for determining where water usage is extreme and where conservation can be targeted effectively.

In identifying places on campus with high water usage, MIT staff have to consider the effect that lasers and other powerful instruments have on overall water usage. Not all institutions have to deal with the utility problems introduced by advanced research equipment, however. To put equipment usage in context, to improve understanding of overall water consumption patterns at MIT, and to make this work more useful to water conservation officials at other institutions, the roles played by other factors that contribute to water usage, such as space usage and weather, need to be explored. Toward that end, in this thesis I propose to develop a single multivariate model that relates water consumption to equipment usage, space usage, lavatory facilities, leakage, and climate.

In preparation for the multivariate model, a subset of available data will be selected, then correlation coefficients will be calculated; high correlations between variables may help determine whether good predictors of water consumption exist. Correlation coefficients will also reveal the extent of possible multicollinearity between explanatory variables. Finally, the assumptions of the regression model will be tested for the selected variables. If these conditions are satisfied, the regression model will be developed, tested, and assessed.

Consideration of information that has been useful in this study and of other information that may be useful for further work will be reserved for the chapter on conclusions and recommendations.

Chapter 4

Method and Procedure

4.1 Selecting Variables for Analysis

With these purposes set, the problem became selecting the appropriate variables to include for the analysis. Some variables were to explain water consumption itself; some were to put water consumption in context with other utility consumption patterns; still others were needed to characterize space usage at MIT, in order to identify targets for conservation on campus.

4.1.1 Ideal Variables

Prior theory provided little guidance in a modeling exercise on exactly this scale. Modeling at such a disaggregated level happens infrequently; seldom is the work published. Nevertheless, models for larger scale areas did point to factors that explained some water consumption patterns generally. Hansen and Narayanan, for example, relied on price, temperature, precipitation, and percentage of daylight hours to explain residential water use [11, p. 578]. Hanke and de Maré modeled residential demand using price, household income, and composition of the population [10]. Dzeigielewski and Boland use income, "conservation behavior", and price to explain urban water use [7, p.101]. Finally, Kim and McCuen relate commercial water consumption to space characteristics, like gross floor area and the length of display windows, as well as to the number of drinking fountains in a store [12, p. 1079].

All of these efforts suggested variables that might prove informative at the institutional level. Weather variables like temperature and precipitation certainly applied as much to university campuses as to residential neighborhoods. Information related to population — the number of people using water, their inclination to use water sparingly — would also help model water consumption. Space characteristics, too, seemed an appropriate item to include in the study, as residential water usage would differ from consumption at athletic facilities, while water usage in offices would differ from usage in laboratories.

The first step in this process involved adapting the variables suggested in the literature to the concrete realities of a research campus. Not that data could be found to match these variables; data serve the needs of workers, not the requirements of researchers. This exercise pushes the researcher to think hard about the problem that he or she confronts. Reflecting in this case on the causes of water usage in itself would inform the analytics that followed.

The most vital statistics, of course, concerned water usage by building. To do the study justice, these numbers needed to be as detailed as possible for as many years as possible. In order to do a thorough time series analysis, monthly or quarterly data should be available, so that seasonal behavior over the course of years could be studied and the effect of irregularities in the data minimized.

If the factors that contributed to water consumption were to be weighed, complementary information needed to be gathered as well. Given the background supplied by the water resources literature, several pieces of information seemed likely to work well as explanatory variables. Chief among these were counts for actual water-using facilities. As the number of water fountains in stores helped to explain commercial water consumption, so the number of toilets, sinks, urinals, and water fountains in each building on campus would help explain institutional water consumption, even if they accounted for only part of the usage.

In addition, again in line with the findings of existing research, some measure of population needed to be included in the study. In an institutional setting, accurate counts for building population contribute to a full understanding of water consumption. After all, total water usage depends on the number of facilities available, but also on the number of people who use them. Water facilities were distributed widely over campus. Heavy use of these facilities was no doubt concentrated in a few locations. The layout of MIT's central building complex, for example, features one long throughway that collects pedestrians from both ends of campus, almost all of whom use the first floor to get to their desitnation. Traffic patterns would probably indicate that lavatories and water fountains along this route got heavier usage than others even on other floors in the same complex.

Water leakage always plays some role in water consumption, and is a key factor in water conservation. The age of pipes and their maintenance history would be of interest for that reason. Measures of water flows, however, would provide more information of direct relevance to this aspect of demand analysis.

In addition, weather and climate affect water consumption. When temperatures are high, people may use more water for bathing, drinking, and swimming. Institutions themselves, especially those with campuses in need of landscaping, consume more water for grounds. Summer months also allow time for cleaning and maintaining large plant facilities, activities that may add considerably to water consumption on campus. At the other extreme, drought conditions can affect water consumption as well. The recent history of water in California, and droughts elsewhere in the United States over the last two decades, many times require rationing that may drastically reduce water use. For these reasons, measures of rainfall and temperature, especially heating degree days and cooling degree days, should be considered in the analysis.

MIT officials, like managers at industrial facilities, face the peculiar challenges to utilities management that the concentrated use of high technology poses. In particular, Physical Plant officials suspect that once-through cooling of lasers contributes significantly to water consumption on campus. Supposing that this hypothesis were true, the number, types, and location of these lasers would need to be considered in the analysis.

It might also be beneficial to see how water consumption compares to that of other utilities. Similar usage patterns between different types of utilities might reveal places where new kinds of equipment that were straining utilities service, or indicate where and when during the year conservation efforts might better be targeted to make the most of limited staff time. In addition, correlations in consumption levels between different kinds of utilities might provide alternative guages of water consumption where usage goes unmetered. Given that both water and electricity are used by people to operate equipment and facilities, for example, some relationship between water consumption and electrical consumption might help facilities managers better understanding monthly water patterns when quarterly billing was normal. For these reasons, it would be useful to have gas, steam, and electricity consumption by building for the same period covered by water records.

Finally, since water metering at MIT is sparse, some tool for learning about water consumption in the absence of meters was necessary. Information about space usage might prove helpful. Residential space at MIT is well-defined and easily identified; dorms have a specific use — housing. Presumably they also have characteristic water usage patterns. Other buildings, however, combine usages for office space, laboratory space, commercial space, and other kinds of space. If water consumption rates for these kinds of spaces could be determined, then those rates could serve as guides for water conservation where nothing is known except space usage. Therefore, variables such as a building's gross square footage, usable square footage, office square footage, and laboratory square footage were important for this study.

4.1.2 Available Variables

With these general variables identified, finding data that was defined as closely to these ideals as possible became the challenge. Not only that, in order to fulfill the requirements of the statistical methods chosen for the project, it was necessary to find satisfactory data for all variables for the same term, preferably for several years. Without time series information for several variables, the contributions that each explanatory variable made to the multivariate analysis would be weak and partial at best. Strong relationships would be easier to certify if reliable data were available.

Utilities Information

Water consumption and electrical consumption data for the years FY80 to FY90 were readily available from the bills issued to MIT's Physical Plant Department. Water bills were available for FY91, as well. Only electrical consumption information was available on a monthly basis, however. Water bills in Massachusetts were issued semi-annually until 1990, when they began being issued quarterly. Billing from the Massachusetts Water Resources Authority to Massachusetts towns and cities happens quarterly. Until the Authority moves to a monthly billing cycle, local water authorities have no reason to bill more frequently. One consequence of this practice for statistical analysis is that seasonal variations in usage become less distinct. Furthermore, since water demand is the topic of study here, all other data must be aggregated to the level for which water data are available. The richness of detail in electrical usage records, therefore, is lost.

Water consumption data had the further disadvantage in many cases of reporting water usage for several buildings at once. Since MIT had no occasion to conserve water until recently, it had little need to monitor its water consumption closely. As long as usage for different parts of campus, and that usage for which MIT was not requireed to pay, was known, this level of understanding sufficed. Knowing more about water usage only imposed more clerical work on a relatively small staff that already found itself busy. The Institute gained nothing from having a more detailed record of its water usage.

Finally, again due in part to MIT's late concern for resource conservation, consumption figures for the early 1980s are less accurate than those for later in the decade. Again, the quality of this information relates to the price of the commodity. Utility meters have been checked for accuracy more frequently as bills have increased in size.

Equipment Information

A completely accurate count of lasers on campus requires either a survey of the departmental headquarters where research was monitored or a survey of all labs on campus. To get at time series data for this equipment, it would be necessary to go through purchasing records to find when lasers had been purchased, when they were used, and when they had been disposed of. The limits of time prevented this deep an investigation into the issue.

A data base maintained by MIT's Property Office filled this need instead. These records, which have information about every item of property that costs more than $5,000, could be queried for items that contained the word 'laser'. Again, the requirements of time series analysis demanded additional information about these items — acquisition date, disposition date, building and room locations. The Property Office kept all these facts on record.

This data, therefore, had the advantage of providing information in electronic form that was needed for a time series. The cost to the study was the undoubted inaccuracy of the information. The Property Office is doubtless seen by researchers as yet another arm of bureaucracy on campus. It is unlikely that the information that goes to the Property Office is completely faithful to the facts. There remains also a question about the level of checking that the Property Office exercises itself in entering this information. Finally, it seems plausible that at least some equipment was disposed of without notice to the Property Office. So acquisition and disposition dates related to equipment were probably suspect. Nevertheless, this was the best information available at the time of the study. No reasonable alternative to this quandary presented itself.

Water-using Facilities

Historical information on the number of sinks, showers, urinals, and toilets in each building, while perhaps available through Physical Plant's preventive maintenance program, would likely prove too voluminous to use within the time available. MIT's Office of Facilities Management Systems, however, maintained records on square footage for all buildings on campus going back before fiscal year 1980. Included in this information was data on lavatory space, which seemed a good proxy for the toilet and washroom facilities.

Even here, the data was incomplete. Only private lavatory space was catalogued in fiscal year 1980; public lavatory space was not. This state continues until FY82, when figures for public lavatory space appear. The figures for these early years were probably as accurate as MIT staff could manage at the time, but subsequent measurements of space have doubtless improved the accuracy of these figures. In part, this improvement in data quality can be attributed to the OFMS' work in automating facilities management information. Througout the 1980s, the OFMS spent a great deal of effort developing a computer package specifically for its work. Since 1985, the OFMS has produced complete reports on campus space usage regularly. Records kept after the middle of the decade therefore change much less and appear much more accurate than records kept before mid-decade.

Space Usage

Three more variables related to specific kinds of space usage were also selected – office space, laboratory space, and classroom space. Other kinds of space usage, such as athletic facilities and health care facilities, were left out. Given that these specialized uses were, like residential space, easy to identify, relatively small in size, and thus less of a mystery than the *terra incognita* that defines utilities usage in the central part of campus, this information was unsuited to this study. Their presence would contribute little to an overall model of water demand, even if they defined places on campus where water usage must occur.

Each of these variables had the virtue of precise definition in the *Higher Education Facilities Inventory and Classification Manual* [24], which guides the measurement of these spaces. Office space comprises conference rooms, office areas that include counters, offices themselves, office service areas, private circulation areas, private lavatory spaces, secretarial and receptionist rooms, and vaults. For purposes of this study, private lavatory space was subtracted from office space and lumped with public lavatory space, which is categorized under mechanical areas.

Laboratory space comprises a variety of different uses, including animal research labs, animal service areas, art studios, dark rooms, drafting rooms, instructional shops, instrument rooms, lab service rooms, stock rooms, lab support shops, music practice rooms, research labs, combined research and office space, and teaching labs.

Finally, classroom space combines lecture hall space, classroom space, and classroom service space.

Building Population

Building population proved particularly difficult to assess. A perfectly accurate history of this variable would require a composite of class enrollment and scheduling around campus and stable office and laboratory populations. The best source for the former information was MIT's Office of the Registrar; the best source for the latter information was the Personnel Office, which keeps records about who occupies which offices on campus. Of these records, only information in the possession of the Personnel Office seemed easily accessible. Even then, the Personnel Office had no historical information available. Even if they did, they refused to help me.

I turned to reasonable proxies for building population. Two came to mind: the number of telephones in a building and the number of parking permits issued to a department. Here again, however, weaknesses in the available data precluded serious efforts to collect data on this variable. Records on telephone usage only went back as far as 1988, when MIT's new telephone system was installed. Previous records were either not available or not kept. Likewise, parking permits had the disadvantage of being distributed by department, not by building. Some effort would be required to correlate department space, building numbers, and parking permits. Even then, the number of parking permits would only approximate the building population, since not enough parking exists at MIT to satisfy every employee.

Stymied by these difficulties, useable square footage was taken as a proxy for population for four reasons. First, useable square footage represented an understood standard measurement that maintained consistency over time. Useable square footage is defined as the gross square footage for a building less the structural area of the building. Second, while gross square footage is the more familiar measure of building space, figures for gross square footage were not as complete for the period of study as the figures for useable square footage. Third, the OFMS maintained relatively reliable measures of useable square footage for the duration of the period under study. Fourth, since building spaces are designed for people, useable square footage represented a reasonable estimate for the number of people who were likely to inhabit a space on campus.

Leakage

The age of water pipes could best be approximated by building age. Going into deeper detail in water system maintenance records would have taken much more time, but also would have required much more complicated calculations. Such information would have involved calculating a weighted average for the age of pipe segments that served particular buildings. It is by no means sure that such records exist, or that such calculations would significantly improve the analysis. Building ages for the years in question, on the other hand, were easy to determine. Construction dates for each building were obtained from the Planning Office; these dates were subtracted from each year under study; and an approximate age for each building for each period under consideration was ready for the analysis.

Weather Data

Finally, the variables that represent weather conditions were easy to pick up. Many articles in water management literature indicated that four variables were relevant — average temperature, heating degree days, cooling degree days, and rainfall. These variables all work well when working with monthly data. In this case, due to the limitations of the water consumption information, data had to be rolled up into semi-annual totals. In such circumstances, average temperature means very little. Heating degree days and cooling degree days, however, lent themselves to such treatment, as did rainfall. Aggregating these monthly figures into semi-annual totals preserved both the meaning and relevance of the variables for the study.

4.2 Quality of the Data

As with all quantitative analyses, the quality of the data was critical to the success of the study. If error rates remain unknown, then greater uncertainty surrounds the conclusions of the study than when error rates are reported. For the more positivistic members of the planning community, studies that provide no measures of the quality of the data used have practically no value.

In this case, water consumption data came from photostats of MIT water bills from 1979 to 1992. After all figures were entered, each figure was checked against the source to make sure that no data entry mistakes crept into the data set. All mistaken entries were corrected as they were encountered. As noted, the accuracy of these readings varied; early records are probably less accurate than later records. Furthermore, some readings were estimated for billing purposes. These estimates were taken as actual values, as it was impossible to eliminate them in favor of more accurate figures. Even so, estimated values numbered 352 of a total of 2,286 readings, a frequency of about only 15%, making the overall reliability of the water readings quite high.

After this, all records were checked to identify buildings for which bills showed no consumption. Many records showed periods where no usage was recorded, but only Building E18 showed no consumption for the duration of the period of study. Consequently, all records for E18 were removed from the data set.

Electrical consumption data, by contrast, were already available in digital form. MIT's Physical Plant staff have made a concerted effort over the last several years to conserve electrical usage on campus. To support this effort, they have analyzed consumption figures using microcomputer hardware and software. I took their data as given, assuming that they were satisfied with its quality. I did, however, have to re-format their data from two-dimensional tables into a style more suitable to data base analysis. This required transposing data, but did not require any alteration of actual values.

Weather data came from the New England Climactic Service in cooperation with the National Weather Service Forecast Office through the generosity of the Forecasting Division of Boston Edison. All these figures were double-checked for accuracy after being entered into a spreadsheet. These figures come from the federal government, so they have a certain authority. That Boston Edison uses these data also recommends them. The main thing to note about this information relates to heating and cooling degree days, which use 65 degrees Fahrenheit for their base. Their main disadvantage is that they were recorded at Boston's Logan Airport, which juts out into Boston Harbor. Temperatures at Logan tend to be somewhat cooler in the summer than temperatures inland, even in Cambridge, and different in the winter time, as well. Even so, the difference should remain relatively consistent for the time period under consideration, and therefore introduce only a small amount of error into the results.

Laser counts were developed in a two step process. First, MIT's Property Office supplied the results of a query to their data base in electronic form. The second step involved parsing these records by means of several perl scripts to capture the name, location, acquisition date, disposition date, and disposition state of each laser. The total number of records produced after this parsing was compared against the number reported by the Property Office to make sure that no information was lost in the process. Then another perl script used the available acquisition and disposition dates to create a time series for the frequency and location of these lasers for the years that pertained to this study. (See Appendix D to review these programs.)

Numbers for facilities space usage proved the most difficult to acquire and to check. This difficulty arose in part from the variety of media on which these records are maintained. Older records, for example, are microfilm copies of computer printouts. The microfilm itself proved to be of somewhat variable clarity, as did the original printouts. Reports produced after 1984, however, were available in very clearly identified and printed bound paper, making entry of this information more convenient.

For the most part, however, the volume of this information and the number of figures selected proved the more troubling part of this data collection effort. To make the most of precious time, and to reduce the amount of checking required, data on facilities for every other fiscal year were entered, beginning with fiscal year 1980. Figures for fiscal year 1991 were also collected to get some insight into how much space figures were likely to change over a period of one year, instead of over two years. Once the accuracy of these figures was checked, space usage figures for odd-numbered fiscal years were interpolated by taking the average of the immediately preceding and succeeding data. Then those figures were duplicated for each year to

Year	Useable SF	Office SF	Class SF	Lab SF	Total Lavatory
1986	0.0%	0.8%	1.9%	0.4%	1.0%
1988	0.1%	1.0%	7.7%	0.4%	0.0%
1990	0.0%	0.1%	1.3%	0.0%	2.7%

Table 4.1: **Error rates in square footage entry by variable for selected years**

provide space usage statistics that corresponded to the available semi-annual data readings.

Once these figures were entered, three years of data were checked to get some sense of the amount of error introduced by keying this information into a spreadsheet. Examining data for FY86, FY88, and FY90 produced these results. Nine (9) errors were made in recording 864 readings for FY86; ten (10) errors were made in recording 846 readings for FY88; and 18 errors were made in recording 980 readings for FY90. Recording error rates therefore amounted to about 1% in FY86, about 1.2% in FY88, and about 1.8% in FY90. What mattered more was the count of square footage that was entered inaccurately. Those findings are summarized in Table 4.2.

Thus, while four years out of the entire seven years of data were not checked, these figures indicate that even the unchecked data can be used with a high level of confidence. Although it should be understood that some mistakes were made, these mistakes should not be so frequent as to undercut the overall validity of the analysis.

To justify the averaging of space usage between years even further, and to identify other problems in the data, the percentage change in square footage figures between available fiscal years was examined. The average, standard deviation, maximum, and minimum values for these percentages were then examined. If the average approached 0.0% and the standard deviation proved to be small, then interpolation would probably not misrepresent actual space usage. (Tables that summarize this information may be found in Appendix E.)

The small changes evident in fiscal years 1986, 1988, 1990, and 1991 for all variables dramatically confirmed the value of averaging. Before 1986, however, either many mistakes were made or much change occurred. This problem was especially evident when looking at useable square footage figures. To alleviate possible concerns about these data, the actual distributions of the percentage changes were examined.

While data for the years that were checked showed much less variation than the data for the years that were not checked, other information from MIT's Office of Facilities Management Systems indicated that actual space usage varied less in the late 1980s than it did early in the decade. The distributions showed that the differences between checked and unchecked data were not great enough to disqualify averaging as a method to develop data for odd-numbered fiscal years. Furthermore, when outliers for FY80, FY82, and FY84 were removed from their respective distributions, variation for these yearscame very close to that of the later years of the decade.

4.3 Aggregating Data

Once these data were collected and checked, they had to be aggregated into files at a level that made meaningful analysis possible. It was readily apparent that a time series analysis of all variables from FY80 to FY90 was possible on a campus-wide scale. That is, campus-wide totals for water and electrical usage, for space usage, for number of lasers, and for weather were feasible to collect. Similarly, since utility usage could be broken down fairly easily by campus locale, it was feasible to break these variables down to a slightly lower level by collecting variables together into campus sectors – East Campus, North Campus, Northwest Campus, West Campus, and Central Campus.

This sectoral analysis had several advantages over treating the campus as one large unit. First, it held out the hope of distinguishing usage patterns within the older buildings that dominated the central portion of the MIT campus from buildings of more recent construction, such as those west of Massachusetts Avenue. Second, since buildings west of Massachusetts Avenue tend to have residential or student activities purposes rather than academic or laboratory usage, this analysis might further help distinguish water usage patterns by building use.

Aggregating data to a finer level, such as the building level, proved more difficult. While information about space usage in all buildings on campus was reasonably available and information about the location of lasers went down to the room level, the information of greatest concern — utilities use — did not. Utilities usage and metering in the main loop of the campus may perhaps best be characterized as a web of valves and a dearth of meters. Facilities are organized in this way for good historical reasons, some of which are detailed above. Water and electrical usage are relatively recent concerns for the Institute and for people in the Boston area. Costs for electricity became an issue only in the 1970s, while costs for water rose even more recently. Furthermore, within the MIT water system, valves provide the main tool for insuring continuous water service to all parts of main campus, even in the event of accidents. And while water valves are likely to remain in the same position from year to year, there is no guarantee that they do. Therefore, water usage for one building may be read off one meter during one year, and off another meter in another year.

In order to avoid these complications, it was determined to treat the buildings in main campus that do not have individual meters as one building with widely diverse space usage. This way, readings for the variable of the greatest interest — utilities usage — would not be lost, but could easily be removed from the analysis to determine how they affected whatever models were developed. Meanwhile, space usage for all buildings on the main loop could be aggregated easily, as could counts for lasers.

The process for creating these records was as follows. A cross-tabulation of building number against all variables was performed to learn which buildings had readings for all the relevant information. Those buildings not on the main campus for which figures about space usage, electrical and water usage, laser usage, and age could be found were selected for study. These numbered twenty-seven (27) and comprised buildings in east, west, north, and northwest campus, assuring a fairly representative geographic spread around the MIT plant. In addition, these buildings comprised a diversity of uses, from primarily office space to predominantly residential usage to commercial and laboratory usage. Finally, utilities for most of these buildings could be isolated to those buildings, so there was little need to combine space usage, utilities usage, and other independent variables from other buildings to represent the space accurately.

In addition, those buildings on the main campus for which these variables were available were separated from the Main Campus and treated as individual buildings, just as buildings for east, west, and north campus were. Six buildings — Building 33, Building 35, Building 41, Building 45, Building 48, and Builing 51 — fell into this category. Figures for the remaining buildings were then rolled up into summary totals for each period and year and identified as one building — Main Campus. Most variables could simply be aggregated; building age had to be calculated by means of a weighted average, however, so that a more representative figure would be present for modeling. This weighted average was calculated by multiplying the building age for each building for each year under study by the useable space for the same building and year, summing these amounts, and dividing the total by the sum of the values for useable area. These aggregated records for Main Campus were then added to the records already created.

Further inspection of water consumption records indicated that central utilities plant water use would distort the statistics for water usage at the building level. Building E40, for example, had water meters both for the useable space and for the utilities facilities located on its roof. A second data set that excluded this information was created to remove the distorting effects that this element of water usage introduced. Electrical usage had no similar metering scheme, so electrical usage could not easily be adjusted to account for this difference in water usage. At the same time, it seemed unrealistic and unwise to reduce electrical usage in the proportion that water use had been reduced. Doing so assumed a relationship between electrical and water usage that had yet to be established, and thus introduced unnecessary biases. Noting this treatment of the data sufficed until the relationship between water and electrical consumption grew clearer.

4.4 Proposed Analysis

Thus, these procedures left this study with four data sets that related the dependent variable of water consumption with the groupsof explanatory variables that concerned themselves with space usage, electrical usage, equipment usage, building age, and weather patterns. One data set dealt with the entire MIT campus for FY80 through FY90; another with the geographic sectors of the MIT campus — East Campus, West Campus, North and Northwest Campus, and Central Campus — for the same time period; two others with water use in individual buildings for this time period, one of which excluded water use by the central utilities plant from Building E40, the other of which included that consumption information.

As with all statistical studies, limits on the availability of data imposed limits on the kind and amount of analysis that was possible. In this case, insufficient information existed to identify precisely where leaks on campus leaks occur and how much water they cost the Institute. Seasonal fluctuations were lost due to the availability only of semi-annual data. Quarterly water data was available for too short a period of time to be helpful. In addition, data for other variables was lacking; electrical usage for FY91, for example, was not readily available.

Despite these limitations, some good analyses were feasible. Indeed, the data proved surprisingly rich. Water consumption data was complete enough to afford fairly extensive univariate analysis over time and within fiscal years. Sufficient data existed to permit some assessment of trends and cycles in water usage, even if seasonality could not be isolated for quarterly or monthly intervals. Therefore a more or less thorough time series study possible, and through this analysis, water consumption patterns might better be identified and understood.

Furthermore, enough supplementary data existed at least to establish hypotheses about where water consumption occurred and where it might be conserved. Correlations between water consumption and other variables, such as electricity or office square footage, promised to provide some guidance for further analyzing water conservation. At the same time, such familiar measures would be comprehensible enough to enable MIT physical plant staff and their consultants to pursue those investigations.

In addition, the data sets were large enough to begin exploring multivariate linear relationships between water consumption, space usage, weather, and use of other utilities. In fact, the data were reliable enough to test those models over time, so that a model developed for one year could be examined in light of the data for another year. Such an analysis held the promise of deepening and strengthening our understanding of water consumption at MIT, and better informing conservation efforts at the school.

Finally, the data were extensive enough to permit many of these analyses on several geographic levels — the campus level, the campus area level, and the building level — without greatly compromising the accuracy of the data, stretching the application of the statistical tools available for analysis, or calling the credibility of the investigator into question. By making analysis of water demand behavior possible from so many perspectives, these data offered a platform for an interesting exploration of water use, an exploration that might make available new tools for water conservation.

Chapter 5

Univariate and Time Series Analysis

With so much data available in so many different forms, it was important to think carefully again about the questions that the analysis proposed to answer. First and foremost, it was necessary to understand what factors contributed most to water consumption itself at MIT. In this respect, the data promised to be fairly informative for at least three reasons. First, data on water consumption were entered accurately and checked thoroughly, so they were faithful to MIT's water bills. The accuracy of these readings were reduced somewhat by the frequency of estimated billing, as well as by some unspecified inaccuracy in metering itself. However, according to Physical Plant, accurate metering had increased with time.

Second, while the time series for water consumption was discontinuous, with information missing for the period that ran from January through June of 1987, it did stretch from FY80 to FY91, a span of eleven years, yielding twenty-two data points. Therefore, in spite of early inaccuracies, a generally complete picture of the long term trend in campus water consumption was available.

Finally, data on water usage were complete in that they accounted for practically all usage on campus over the period under investigation.

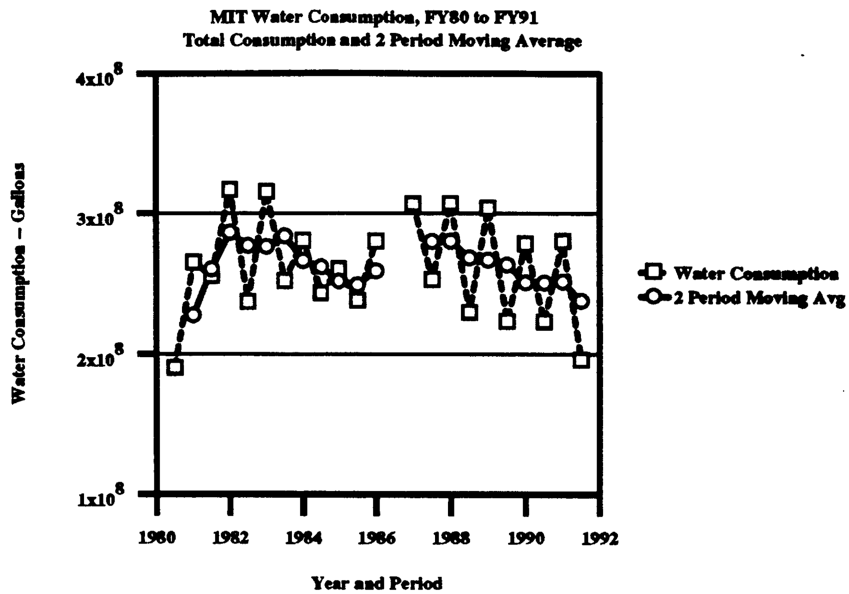

Figure 5-1: **MIT Campus-Wide Water Consumption, FY80 to FY91**

5.1 Campus-wide Water Consumption

Analysis began by running descriptive statistics about water use for the entire MIT campus for the period running from FY80 to FY91 and by graphing this time series to discern the long term trend, cyclical behavior, seasonality, and irregularities in the data. (The actual time series data may be found in Appendix A. See Table 5.1 for the summary statistics. Figure 5-1 presents the graph of the time series.)

	Gallons of Water
Number of Records	22
Average (Ave.)	261,074,080
Standard Deviation (STD)	35,732,430
Maximum (Max.)	317,025,000
Minimum (Min.)	190,622,250

Table 5.1: **Summary Statistics on MIT Semi-Annual Water Usage**

These figures lost some of their meaning when there were few numbers about water consumption elsewhere available for reference. Basic time series techniques provided perspectives that the numbers by themselves could not, however. Water usage fluctuated between approximately 200 million and 300 million gallons semi-annually, but tended toward the mean of these two extremes without revealing any dramatic upward or downward trend overall. Cyclical behavior proved rather more evident than trend, as usage declined toward the middle of the decade, then climbed again slightly between FY86 and FY89 before declining again toward the end of the 1980s. This cyclical behavior may have followed from drought conditions during the middle of the decade, and from purposeful conservation efforts near the end of the 1980s.

It is worth noting, however, that even though this time series remained fairly stationary, consumption varied by as much as 19.2% between the year of greatest consumption, FY83, and the year of least consumption, FY91. Furthermore, the last five years of figures indicated a steady downward trend in consumption, as total usage declined from 560 million gallons in FY87 to 476 million gallons in FY91, a 15% decline during that term.

Campus-wide water usage did show one other pattern — a regular decline during the second half of every fiscal year, indicating some sort of seasonality on campus. Since the first half of the fiscal year stretched from July to December, a period that encompassed both summer vacation and part of Christmas vacation, added campus population seemed an unlikely key to explaining this phenomenon.

In order to understand the seasonal fluctuations apparent in these data better, two parts of a time series analysis were run. First, autocorrelation functions were created using lags ranging from one period to eight periods. While autocorrelation tests are better adapted for monthly or quarterly data, they would in this case help articulate patterns in water usage between periods, and perhaps illuminate later analysis on

Lag	Gallons	Standard Error
1	-0.430	0.199
2	0.528	0.195
3	-0.478	0.190
4	0.323	0.185
5	-0.382	0.179

Table 5.2: **Autocorrelation Functions for MIT Water Consumption**

usage at less aggregated levels of consumption. Second, using the results of the autocorrelation test, a two-period moving average was developed to remove seasonality from the data and develop a clearer picture of the long-term trend in utilities use for water and electricity.

Autocorrelations for the first five lags are presented in Table 5.2. The first four autocorrelations are statistically significant at a level of .05. Notice that the strongest autorcorrelation is at Lag 2, reflecting seasonality.

Thus, the patterns for usage evident in the graphs find corroboration in these measures of correlation between records for different periods. Water usage tends to vary markedly between seasons; odd-period lags see uniformly negative correlations between figures, while even-period lags show consistently positive correlations.

It was impossible to delve any further into this phenomenon with existing water data. Quarterly water consumption records for FY90 and FY91 could provide some insight into this problem, but were inconvenient to assemble. Instead, on the assumption that this seasonal pattern applied to all utilities and not just to water, a quarterly time series for electrical consumption that covered approximately the same period of time — FY80 to FY90 — was examined to help understand seasonal consumption in more detail.

This time series provided some insight. Electricity showed a significant jump every summer, probably due in large part to air conditioning. Still, one would expect population on campus to decline during the summer months, and electrical consumption to decline at least somewhat along with it. If this proved not to be the case, then either utilities usage depended more on MIT facilities than on population or population declined somewhat less than one would expect.

A review of figures for MIT's enrollment indicated that campus population may fluctuate less than one might suspect. Over half of the student body consists of graduate students [19, p. 10], for example, many of whom work winter and summer on campus. Furthermore, graduate students at MIT during the summer have fewer distractions from research than they do during the school year; they likely spend more time there. Add to this that MIT employees, including faculty, make up almost half the campus population of about 17,000 people and one realizes that campus facilities are almost always in use. Thus, it is entirely reasonable for both water and electrical use to increase during the summer instead of declining.

With the two-period seasonal variation confirmed, a two-period moving average was developed to remove seasonality and to smooth irregularities in this time series so as to clarify the trends and cycles in water consumption at MIT. The moving averages were then superimposed on the original graphs for purposes of comparison. The same work was done on the figures for utilities use per square foot to see whether any further distinctions could be drawn between gross resource usage and usage per square foot. The results of these analyses are presented in Figure 5-2.

The results of this exercise proved interesting, and should be encouraging to MIT staff, especially as regards water conservation. The cyclical pattern present in the water consumption data became much more pronounced and noteworthy. Water usage clearly declined between FY83 and FY85, then rose again before declining after FY88. What should encourage Physical Plant staff more, however, is the graph for water consumption per square foot, which shows a steady decline since FY88. This trend

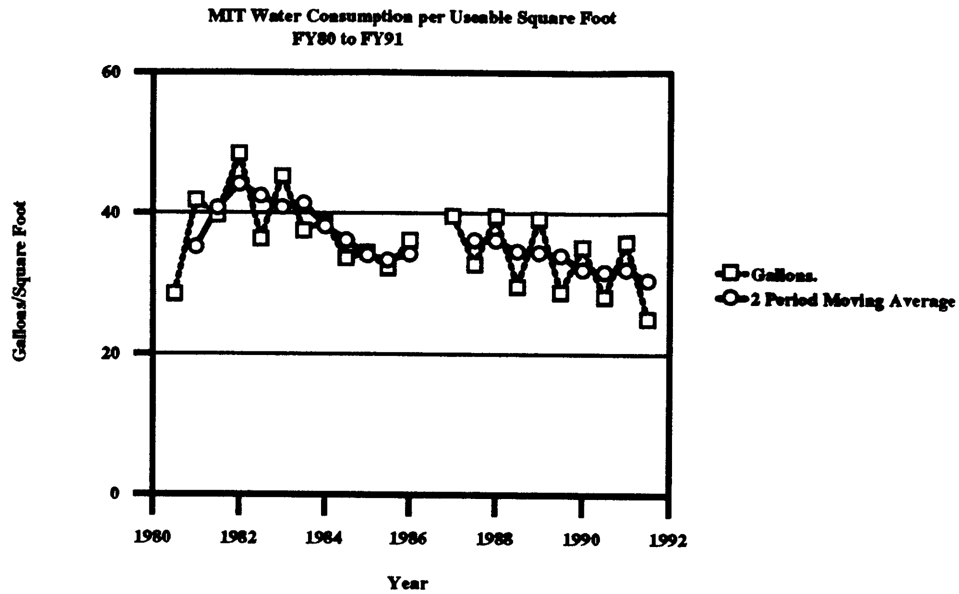

Figure 5-2: **Usage per Square Foot and Two-Period Moving Averages for MIT Campus-Wide Water Use, FY80 to FY91**

indicates either that water was being used more efficiently beginning with FY89 than at about any other period under study or that campus usage patterns are changing. If the former, then Physical Plant may be doing something right in managing its water resources better; if the latter, then Physical Plant's water conservation strategy and budgeting may need to be altered to fit changing realities.

To settle this last question, overall space usage was analyzed to see whether changes in the overall composition of the campus might help explain reductions in water usage. The results, presented in Figure 5-3, testify to a mild long-term increase in office space and more noticeable decline in laboratory space. Classroom space and lavatory space as a percentage of useable space have remained stable during the period under study. Thus, while this establishes no direct relationships between space usage and utilities consumption, it at least supports the hypothesis that changes in space usage may explain some changes in utilities usage for the period under study.

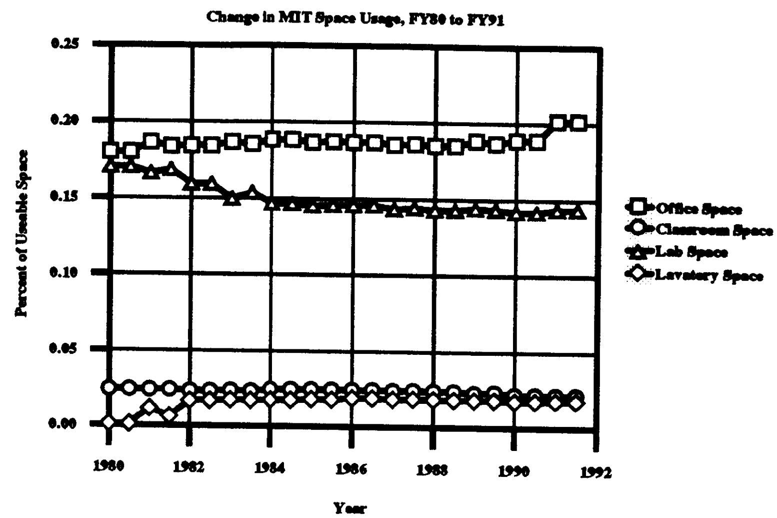

Figure 5-3: **Percentage of Kinds of Space Usage at MIT, FY80 to FY90**

Finally, in order to begin understanding water usage in terms of space usage on campus, a new variable — Gallons per Useable Square Foot — was calculated and plotted. Given the relatively small amount of construction on campus over the course of the period under study, one would expect to see little difference between usage patterns for raw usage and per square foot usage. Such was the case with overall campus usage. While it brought no new information forward, this statistic did create a standard unit of analysis that would be useful for comparing usage rates in the analysis to come. (See Table 5.3 for the summary statistics on this distribution.)

5.2 Water Consumption by Section of Campus

The next phase of the study was an analysis of campus water usage by each region of campus. A second data set was employed for this purpose (see Appendix B for the actual data). Water usage for East Campus was distinguishable from usage on West Campus, both were distinguishable from Central Campus, and so on. Water consumption data here covered the same time period, FY80 to FY91, as the previous data set. The primary purpose of this analysis was to understand water usage patterns for Main Campus, comprising all buildings west of Ames Street, east of Massachusetts Avenue, and south of the train tracks and Main Street. Some of the behavior that appeared in the first phase of the analysis could be further explored, as could the question of changing space usage and its relationship to water consumption.

The first step, again, was to develop descriptive statistics for each of the distributions under consideration — East Campus, Main Campus, North Campus, Northwest Campus, and West Campus. These appear in Table 5.4. The extent to which utilities usage on Main Campus overwhelms all other sections of campus is obvious. The semi-annual average for water usage on Main Campus is twice as large as the next largest water-using section of campus, and itself accounts for almost half the total usage of campus. This disparity in consumption is explained largely by a corresponding disparity in square footage. Main Campus takes in over 3 million useable square feet, roughly half the total useable square feet for the entire campus. For this reason, it *should* account for a significantly larger portion of water usage than other sections of campus.

As this fact implies, more can be gathered about water usage across campus from examining usage per square foot than from comparing raw numbers only. Table 5.5 presents the average water consumption for each sector of campus for the period

	Gal/Useable SF
Count	22
Average	35.78
STD	5.62
Maximum	48.54
Minimum	25.11

Table 5.3: **Summary Statistics on Semi-Annual Water Usage per Useable Square Foot**

	East	Main	North	Northwest	West
Count	22	22	22	22	22
Avg	39,829,057	121,867,295	22,920,375	17,431,875	57,325,909
STD	9,764,021	22,345,117	14,716,374	4,758,011	5,821,993
Maximum	61,446,000	165,483,000	59,198,250	23,745,750	66,743,250
Minimum	23,033,250	77,726,250	852,750	2,028,750	42,704,250

Table 5.4: **Descriptive Statistics for Water Usage by Campus Sector, FY80 to FY90**

for which data is available. Comparing these figures with those available for the entire campus indicates, as one would expect, that Main Campus uses water at above average rates, but not extraordinarily above average. What is particularly surprising, however, are the rates for Northwest Campus and North Campus, where campus space is comparatively small. To site one measure, in FY90, the useable square footage for Main Campus amounted to just over 3.4 million square feet. East Campus had almost 1.5 million square feet, West Campus over 2 million square feet. North Campus and Northwest Campus each comprised only about 500,000 square feet. Total water usage for both areas in that year amounted to 99.7 million gallons, however, just 5 million gallons shy of West Campus usage and 50% more than usage on all of East Campus.

To better articulate these findings, another time series study looked at variations in semi-annual water use over time by campus sector. Autocorrelation statistics were also run to determine whether seasonality appeared uniformly across campus sectors as it did for the campus as a whole.

One purpose of this part of the exercise was to discern patterns of water usage

	East	Main	North	Northwest	West
Ave. Gal/Useable SF	31.49	36.76	52.23	37.84	31.87

Table 5.5: **Average MIT Water Usage per Useable Square Foot by Campus Section**

outside of Main Campus that might inform conservation efforts *for* Main Campus. The time series for the central campus therefore anchored comparisons with other time series. As the scale of water usage on Main Campus dwarfed usage for any other part of campus, comparing raw usage over time would not be useful. Water usage per useable square foot in gallons provided a better unit of analysis.

In cycling through graphs of these time series, no one section of campus resembled Main Campus very strongly. Main Campus encompasses so many different kinds of space that its usage defies simple characterization. For this reason, one tends to see similarities where one wants to see similarities. The dominance of water usage in this part of campus showed through, however, as only Main Campus displayed the cyclical pattern of usage present during the four years between 1984 and 1988 that also appeared in the campus-wide time series. Water usage everywhere except North Campus trended slightly down, although Main Campus and West Campus seemed to show the least decline over the last few years of the decade. Declines were most dramatic in Northwest Campus; extraordinary increases were recorded for North Campus, due largely to the presence of central utilities plant facilities there. This pattern may reflect a problem with the data, or simply reveal a growing influence of plant utilities practices in this section of MIT. East Campus and West Campus showed a comparable intensity of use late in the 1980s, with usage averaging between 20 and 25 gallons per square foot after FY89; Northwest Campus also approached these levels of water usage during the last couple of fiscal years in the decade.

Breaking the data down to the campus sector level at least permitted slightly better understanding of the seasonal component of the time series for water usage from sector to sector. With so much information available, however, it was difficult to gather this understanding from graphs, so autocorrelation tables and correlograms again provided better tools for this analysis.

The two-period seasonal pattern evident in overall campus water use repeated itself selectively within each of the campus sectors. West Campus and Northwest Campus, for example, showed almost no seasonality in water usage, while the remaining sections of campus did, with East and North Campuses showing strong seasonality. Space usage typical of these sections of campus might well account for these variations. West Campus, having primarily residential facilities, contained very little lab, office, and classroom space. The population of West Campus was likely to remain at about the same level from one semi-annual period to another, and the activity characteristic of this part of campus was unlikely to change between the summer-fall period and the winter-spring period. East Campus and North Campus, by contrast, house sizable office and laboratory spaces, which may show usages different during the summer than during the school year — or just as intense year round, accounting for higher water consumption during the summer than during the winter and spring.

5.3 Water Usage by Kind of Space Usage

The preceding work indicated more and more that the kind of space usage accounted for water consumption rates. At this point, it made sense to calculate water usage per square foot for distinct kinds of space usage on campus. A third data set formed the basis for this phase of the project (see Appendix C for the raw figures). Initially, it seemed reasonable to assign buildings to one of four categories — dormitory use, office use, laboratory use, and indeterminate use. The first three classes of building usage were easy to conceive and well defined, thanks to the definitions provided by the *Facilities Inventory and Classification Manual* of 1973. Indeterminate use provided a catch-all category for those buildings that did not easily fit into the other groups.

Dormitory space usage was easily identified. They were known by name. Also, dorms contained almost no lab and office space. Determining which buildings were devoted to lab activities and which to office use was slightly more difficult, however. Lab space almost never took up all of a building. Instead, labs and offices frequently appeared together in the same building in varying proportions. To get around this difficulty, I adopted a simple rule of thumb. Labs were defined as buildings where the percentage of laboratory space equalled the percentage of office space. It was assumed here that offices served the labs, rather than the other way about, and that lab activities dominated water usage.

Conversely, if the percentage of office space greatly outweighed the percentage of lab space, then I assumed that office activities predominated. Frequently, these buildings were easy to identify, as lab space was either absent or so small as to be insignificant. In Building E40, for example, approximately 60% of the useable space was devoted to office space. NW16 was the office building that had the highest percentage of lab space, at approximately 4%.

For places where neither office nor lab space predominated, buildings were assigned to an indeterminate category. In these cases, lab and office space were either equal in proportion or so reasonably balanced as to prevent the assumption of one kind of usage or another. The results appear in Table 5.6.

Averages for water consumption per square foot of useable space were then computed for these buildings. The results proved quite interesting, and promised to give a simple, useful rule of thumb for predicting water consumption by space type. Average water consumption per square foot of dorm space came to about forty-two (42) gallons; of office space to approximately thirty-six (36) gallons; of lab space to approximately thirty-two (32) gallons; and of indeterminate space to about twenty-three (23) gallons. Thus, each type of space usage seemed to possess a characteristic intensity of water consumption that would be useful for assessing water usage in particular spaces around campus and for setting priorities on conservation measures.

These initial calculations proved to be high, however. The estimated consumption per square foot for office space incorporated figures for W91, an office building with unusually intense water usage. Its average rate of water consumption per square foot

Building Number	Name	Category
E2	Senior House	Dorm
W61	MacGregor House	Dorm
W70	New West Campus House	Dorm
W71	500 Memorial Drive	Dorm
W84	Tang Residence Hall	Dorm
33	Guggenheim Aeronautical Lab	Indeterminate
35	Sloan Laboratory	Indeterminate
45	Animal Care Facility	Indeterminate
51	Sailing Pavilion	Indeterminate
E10	Unnamed	Indeterminate
E15	Wiesner Building	Indeterminate
MC	Main Campus	Indeterminate
N42	Graphic Arts Building	Indeterminate
N51	Unnamed	Indeterminate
N57	Unnamed	Indeterminate
NW17	Unnamed	Indeterminate
NW30	Albany Street Central Storage	Indeterminate
W31	Dupont Athletic Gym	Indeterminate
W45	Unnamed	Indeterminate
W59	Unnamed	Indeterminate
41	Unnamed	Lab
45	Animal Care Facility	Lab
48	Parsons Laboratory	Lab
E17	Seely G. Mudd Building	Lab
E20	Unnamed	Lab
NW13	Nuclear Chemistry Building	Lab
NW14	National Magnet Lab	Lab
NW21	Nabisco Laboratory	Lab
W11	Center for Advanced Visual Studies	Lab
W74	Solar Demonstration Building	Lab
E32	Unnamed	Office
E40	Muckley Building	Office
E51	Unnamed	Office
NW16	Plasma Fusion Center	Office
W91	Unnamed	Office

Table 5.6: **MIT Buildings by Type of Space Usage**

for FY86 to FY90 was almost 116 gallons; the average for all the other office buildings was 90% less, at about fourteen gallons. A few outliers among the figures for the other categories of building types likewise raised the mean figures for water consumption per square foot.

These means were re-calculated for each group without these outliers. Records for Building W91 were removed from the calculations for office space, while three cases were taken from the records that pertained to indeterminate spaces and one case was eliminated from each of the other two data sets.

The consequences of this change were dramatic for office space, and mild for all other categories of space. Average water usage per square foot dropped across the board, but the average for office spaces dropped to a level that squares more with the kind of water usage one would expect in an office, at 14.5 gallons per square foot. The average for dorm, lab, and indeterminate spaces went down about two gallons per square foot each, resulting in averages of 40.1, 30.1, and 21.3 respectively.

A one-way analysis of variance was then run on all four groups to determine whether the differences between these averages were statistically significant. Again, when W91 was removed from consideration, the results of these tests confirmed that three of the categories differed from each other at the 95% confidence level with an F ratio of 7.7 and a probability value of 0.0001. Water usage in offices was much lower than water usage in all other categories of buildings; water usage in laboratory spaces was higher than in office spaces, but lower than water usage in dormitories. Differences between laboratory spaces and indeterminate spaces were not significant, however, indicating that this distinction was too fine for the scope of this study. Apparently, except when office spaces are isolated from lab spaces, lab space and office space complement each other on the MIT campus.

Therefore, buildings that had been included in the indeterminate category were

Group	Count	Mean	STD	Std. Error	95 Percent Confidence Interval		
Dorms	45	41.7	16.4	2.4	36.8	to	46.6
Lab/Office	202	26.6	28.8	2.0	22.6	to	30.6
Office	34	14.6	15.4	2.6	9.2	to	19.9
Total	281	27.5	26.8	1.6	24.4	to	30.7

Table 5.7: **Analysis of Variance Results for Three Building Types**

combined with buildings identified as laboratory facilities. New averages were calculated, and another one-way analysis of variance was undertaken to learn whether this revised scheme made more sense of water consumption. The resulting averages are presented in Table 5.8. The analysis of variance indicated that each of these groups differed significantly from one another at the 95% confidence level wth an F ratio of 11.2 and a probability value of 0.0000. As one would expect, average consumption per square foot remained unchanged for office and dormitory use, while the average for a combined space type comprising office and lab usages moved to a spot between the old averages for lab and indeterminate space types. Results are summarized in Table 5.7.

One advantage of this altered form of space categorization was the lack of overlap in the confidence intervals for the different kinds of space. Conservation officials should be able to use these intervals in estimating upper and lower bounds of typical water consumption for each type of space usage. These estimates should further help them to assess whether actual water consumption for particular spaces transgresses the bounds of reasonable usage and set priorities for their conservation efforts accordingly.

Chapter 6

Multivariate Analysis

As the analysis proceeded, space usage seemed to provide a better and better key to understanding and predicting water consumption at MIT. It remained to be shown, however, how much specific factors contributed to overall water demand. Given MIT's technical research mission, it seemed likely that labs and offices together might account for large amounts of water usage per square foot of campus. How much they contributed in comparison with other factors for water consumption still remained to be determined. In addition, these figures gave little insight into how equipment usage, specifically once-through cooling for lasers, contributed to water usage on campus. The preceding work therefore provided background for a series of multivariate analyses.

Two multivariate models seemed in order. One attempted to explain the *rate* of semi-annual water consumption in gallons per square foot. The other attempted to explain *total semi-annual usage* in gallons. Both models together promised to give Institute conservation managers additional tools for estimating water usage and targeting water savings.

Both models attempted to explain water consumption on campus in terms of five factors — building space usage, equipment usage, lavatory space, leakage, and climate — although each model used slightly different data to represent these factors. In forecasting water consumption rates, classroom, office, and laboratory space percentages for each building represented building space; in forecasting total water usage, raw square footage figures served the same function. The same technique applied when representing lavatory space: percentages went into the rate model, raw square footage into the total usage model. Each model used the same dummy variable to indicate whether or not a building was a dorm.

The number of lasers in each building under consideration in this case represented equipment usage. If this statistic worked poorly for the rate model, then the number of lasers per useable square feet could be created easily as a substitute.

Literature on water resource management and common knowledge of Boston's water systems indicated that leaks were a likely source of water consumption. Leakage took building age as a proxy variable.

Finally, as the preceding time series analysis and water consumption analysis demonstrated that seasonality played a role in consumption, climactic variables were included in the analysis, represented by heating-degree days, cooling-degree days, and precipitation measures.

6.1 Choosing the Years of Study

The buildings under study had been selected at the time of data aggregation. They consisted of those buildings for which both water and electrical readings, space readings, and equipment usage figures were available. Data for these variables existed for all years between FY80 and FY90. As when calculating water usage per square foot for specific building types, however, it was necessary to decide which of these years to include. The time series analysis for campus-wide water consumption, as well as the directions from Physical Plant staff, indicated that figures collected later in the decade were both more accurate and more relevant than figures collected earlier in the decade. With the exception of figures for North Campus, they also proved to be more stable overall at the campus-section level later in the decade.

Likewise, space usage information proved to be both more complete, more stable, and more reliable later in the decade than earlier in the decade. Office of Facilities Management Systems information indicated that building construction slackened considerably after mid-decade. Furthermore, during the data collection phase of the project, space usage figures had been collected and checked for FY86, FY88, and FY90. Bounding the study period by FY86 and FY90 left only two years worth of calculated space data in the data set, and removed from consideration several years of data with inaccurate or questionable figures that promised to create trouble for the analysis.

Since these categories — water usage and space usage — represented two of the most important pieces of information available, it seemed best to take a conservative approach when selecting the data and to use only those data known to be of the best quality. For this reason, and to make better comparisons between different analyses possible, the years FY86 to FY90 were selected for study.

6.2 Linear Correlations

Once the period of study for multivariate analysis was set, it was necessary to test whether linear relationships existed between the dependent variables — gallons of water per square foot and gallons — and each of the explanatory variables. A series of correlations were run for each semi-annual period under investigation and for the period as a whole for each of the variables of concern. (All correlation matrices may be found in Appendices F and G.)

In looking at the correlations for the period as a whole, including figures for Main Campus, very high correlations appeared between the number of lasers and gallons used. A dummy variable that indicated whether a building was on or off Main Campus showed the same strong relationship to water usage. In this case, when a building was on Main Campus it was likely to show high water consumption. Both of these correlations were significant at the 99.9% confidence level.

Very high and equally significant correlations also existed between any kind of specific space usage — measured by classroom square footage, laboratory square footage, office square footage, and useable square footage itself — and water usage. As expected, total lavatory square footage and water consumption also proved to be highly correlated. Other variables — a time parameter to represent the decline in consumption over the years of study; all three of the climate variables; building age; and two dummy variables, one pertaining to seasonality, the other to dormitory use — all showed only slight correlations with raw water consumption.

A consistent problem with the data was the extent to which statistics for Main Campus overwhelmed all others. Correlations between these same variables declined appreciably when figures for Main Campus were excluded. Many of the same variables — useable square footage, office square footage, classroom square footage, laboratory square footage, and total lavatory space — still proved to be significantly correlated to water consumption. The number of lasers, too, remained significantly correlated to water consumption. Two variables, however, increased in strength of correlation. They were building age, which showed a negative correlation, and the dummy variable for dormitory use, which showed a positive correlation.

Correlations between variables relevant to water usage per square foot of useable building space, by contrast, proved to be much lower across the board, with generally lower statistical significance. Of the thirteen parameters under consideration for inclusion in the model, only three — the dummy variable for dorm usage, the percentage of classroom space, and the percentage of lavatory space — proved to be significantly related to water consumption per square foot. Of these, classroom space had the strongest correlation at -0.206, followed by the percentage of lavatory space at 0.162, and dormitory usage at 0.157. Variables that measured seasonality, such as heating- and cooling-degree days and the dummy variable, shared about the same level of correlation with water consumption rates. The correlation for building age ran slightly behind these variables in strength.

When this test was run again without records for Main Campus water consumption, the same variables again showed about the same levels of correlation with water consumption rates.

The results of these analyses proved somewhat surprising. For overall campus consumption, one would expect lab usage to share at least a mildly positive association with water consumption, especially when considering the rate of water consumption. Likewise, one would expect the number of lasers to demonstrate a stronger correlation to water rates. Neither proved to be the case, although the correlation between the number of lasers and usage per square foot did change markedly when Main Campus usage statistics were excluded from consideration.

6.3 Designing Multivariate Models

Given the strength of the linear relationships between the independent variables and raw water consumption, a multivariate model that related these factors to gallons of water use seemed justifiable. A simple pooled time-series regression procedure would satisfy the assumptions of the multivariate regression model and permit the analysis to proceed. This technique was again justified by virtue of the data, which showed only slight variations over the period of study. Since variations were slight, data for all the time periods under consideration could be treated as data for one large period of time, provided with a variable present to account for the passage of time. A time variable that incremented with every fiscal year satisfied this requirement.

In light of this assumption, a multivariate model that could be used to forecast water consumption rates also seemed to be in order, despite the weakness of simple linear relationships between the variables. Although this weakness would necessarily produce a model with small predictive power, it seemed to be of value as a starting point that others could refine in due time.

6.3.1 Model for Water Consumption

Selecting the Variables

The time variable mentioned above was the first parameter included in the model. After that, it was necessary to deal with parameters related to space. The correlation coefficients between the variables pertaining to space usage indicated a high degree of multicollinearity. Office square footage, classroom square footage, laboratory square footage, and total lavatory space all exhibited correlations with useable square footage significant at the 99.9% confidence level. Including more than one of these variables was likely to weaken rather than strengthen the model, as any model that incorporated all these elements would be unable to explain water consumption very clearly. Since useable square footage had the highest correlation to water consumption of any of these variables and had more general usefulness in assessing water usage around campus, it was selected.

Unlike variables that recorded square foot measures for particular buildings, the dummy variable on dormitory usage evidenced no multicollinearity. Dormitory water consumption was also demonstrably distinct in quality from other uses. The figures developed earlier demonstrated that dorm usage was more intense than other spaces on campus. Dorms contributed heavily to water usage. Their contribution needed to be represented in any model for campus usage. These reasons justified including this variable in the final model.

The number of lasers per building, while strongly correlated with useable space, likewise represented an aspect of water consumption that deserved to be included in the model. Its high correlation to raw water usage was due in part to the overwhelming presence of lasers on main campus and the high association between main campus and water usage. Nevertheless, the correlations that resulted from removing cases for Main Campus indicated that lasers still contributed to water usage at a high level of statistical significance. Therefore, the number of lasers was included in the model.

The variables that remained for inclusion in the model all showed low correlation with water usage. Nevertheless, the seasonal pattern in campus-wide water consumption seemed important to the forecasting model. No one parameter among cooling-degree days, heating-degree days, and the seasonal dummy variable seemed best correlated with water consumption, but all seemed important. Cooling-degree days, for example, were relevant in forecasting summer water usage; heating-degree days were useful for estimating winter water usage. The dummy variable for seasonality provided an instrument that accounted for variations between the semi-annual periods identified through the time series analysis. All three of these variables were therefore included in the model.

Predicting the Outcomes

This model attempted to model raw water consumption on the basis of five factors — time, the size of buildings, residential or non-residential building usage, climate, and equipment. Taking the results of the preceding work into account, one would expect water consumption to increase with useable square feet, since larger buildings would house more people who would use more water. In addition, the draw that once-through cooling of lasers imposed would increase water use. Seasonality and cooling-degree days pointed to summer use, which tended to show increases in consumption. Finally, dormitory usage reflected an intensity of water consumption that would increase total usage.

Two variables were expected to drive consumption down, however. First, water usage would tend to decline with heating-degree days, in part because there would be less reason to water lawns, less opportunity to perform water intensive maintenance on plant facilities, and perhaps less concentrated use of laboratories and offices. Second, Physical Plant's existing conservation efforts over time would yield further water savings that reduced consumption.

Assessing the Model

Selecting all records that had any reading for gallons greater than zero from the chosen data set provided 290 cases. The variables utilized were

G = Gallons
U = Useable square footage for a building
L = Number of lasers in a building
D = Dummy variable identifying dormitory usage
S = Dummy variable identifying seasonality
H = Number of heating-degree days for a semi-annual period
T = Time variable representing the fiscal year in sequence
C = Number of cooling-degree days for a semi-annual period

The regression equation esitmated from the sample was

$$\hat{G} = 301,125.76 + 58.24U - 125,322.62L - 948,657.73D + 927369.50S - 358.32H - 73,716.68T - 280.02C$$

The R^2 associated with this model was 0.967, as was the value for the adjusted R^2. The F-value was 1198.84, with a probability value of 0. The t-values for each of the variables appear in Table 6.1.

Unfortunately, the signs of some of the parameter estimates came out counter to expectations. The model indicates, for example, that campus-wide water usage goes

Variable	t-value	Standardized Beta
Useable square feet	16.341	1.571
Number of lasers	-6.175	-0.596
Cooling degrees	-0.092	-0.002
Heating degrees	-0.427	-0.014
Dorm dummy variable	-1.388	-0.017
Time	-0.411	-0.005
Season dummy variable		0.022

Table 6.1: **The t-values and Standardized Beta Coefficients, Including Main Campus**

down as numbers increase — an unreasonable outcome, unless laser technology has changed so drastically as to require markedly less cooling in the last several years. (Yet some grounds may exist for that hypothesis. According to records from the Property Office, the number of lasers in central campus grew by over 30% from 1984; total water usage over the same period declined.)

The same phenomenon appears with cooling-degree days and the dormitory dummy variable. The model indicates that water consumption should go down with the summer season; the time series model shows the opposite. The model indicates that water consumption goes down with dormitory usage, but the intensity of water use in those spaces should push water consumption up.

The presence of records for Main Campus proved again to be a complicating factor. When the regression equation was re-run excluding information about Main Campus water consumption, the following model was generated.

$$\hat{G} = 3836034.84 + 25.66U + 100936.28L + 1915224.91D + 23577.20S - 151.12H - 84583.77T + 543.09C$$

Here the signs are what one would expect for each of the terms. The R^2 value

Variable	t-value	Standardized Beta
Useable square feet	7.165	0.414
Number of lasers	5.834	0.294
Cooling degrees	0.349	0.042
Heating degrees	-0.354	-0.045
Dorm dummy variable	4.746	0.264
Time	0.930	-0.042
Season dummy variable	0.004	0.038

Table 6.2: **The t-values and Standardized Beta Coefficients, Excluding Main Campus**

for this model was .499; the adjusted R^2 was .486. The F-value was 38.85, with a probability value of 0. t-values for the variables appear in Table 6.2.

Since both models predicted total campus semi-annual usage based on the available data set, an appropriate test was to return to the data to apply each model to one period of the data. In this case, both models were tested against each period of 1990 to get some sense of how well they predicted water consumption over the course of an entire year. The results of this analysis appear in Table 6.3.

Thus, while the model that included values for Main Campus proved to be very good at predicting semi-annual campus-wide water consumption, it supplied a weak tool for ranking the factors that contributed to water consumption at MIT. Considering the same data without the figures for Main Campus provided a better tool for understanding the factors that contributed to water consumption, but a less reliable instrument for predicting total water usage.

Year	Actual Use	Estimated Use	% Difference
With Main Campus, Period 1	150,696,000	147,072,016	2.4%
Without Main Campus, Period 1	53,409,000	29,300,493	45.1%
With Main Campus, Period 2	188,067,750	186,839,933	0.7%
Without Main Campus, Period 2	62,954,250	42,092,789	33.1%

Table 6.3: **Results of Water Consumption Models Applied to 1990 Data**

6.3.2 Model for Water Consumption Rates

Selecting the Variables

Developing the model for water consumption rates involved a similar process. Correlations between the dependent variable, gallons per square foot, and the independent variables mentioned above provided the starting point for the analysis. Again, since a simple pooled time-series analysis provided the analytical tool for these data, it was necessary to include a variable that accounted for the effect of time on water consumption. The same variable used in the previous model served in this one.

Three space-related variables merited consideration on the basis of the statistical significance of their correlations to water consumption rates — the dummy variable for seasonality, the percentage of classroom space in a building, and the percentage of lavatory space in a building. Unfortunately, all of these variables were highly correlated with one another, giving rise to the possibility of multicollinearity in the resulting model. Knowing that water usage was most intense in dormitories, however, it was foolish to exclude an indicator that would help explain that variation in water usage. Furthermore, knowing how much lavatory space contributed to water consumption across campus, it was also difficult to exclude a variable for the percentage of lavatory space. At the same time, classroom space seemed a likely indicator for very low water usage. It also showed a fairly weak correlation with dormitory usage. These reasons gave justification to including all three of these variables in the model, at least initially. In order to see how much these variables explained in comparison to the remaining space variables, the percentage of office space and the percentage of laboratory space, both of the remaining variables were included for study, too. Once the model was developed, it could be adjusted by eliminating one of these variables as necessary

Heating- and cooling-degree days, along with the dummy variable for seasonality were each included in this model for the same reasons they had been included in the previous model — each variable accounted for a different aspect of the influence of weather on water consumption. The number of lasers, likewise, accounted for equipment usage and needed to be included at least in a first approach to this problem.

Predicting the Outcomes

Correlations and common sense reasoning again provided clues about the likely outcomes for this regression model. The dummy variable that indicated seasonality would increase intensity of use, as would the dummy variable for dormitory use, the variable for cooling-degree days, the variable for number of lasers, and variables for the percentage of lab space and percentage of lavatory space in a building. Measures for heating-degree days, time, and percentages of office and classroom space would tend to counteract these variables, driving the intensity of water use down.

The correlation table, combined with the results from prior analysis, gave some clues as to how much one of these factors might dominate others. Clearly, sources that contributed directly to water consumption, such as dormitory space and lavatory space would carry more weight than variables that influenced water consumption more indirectly and in selected locations on campus, as the weather-related variables did.

Weighing the influence of the number of lasers proved to be a rather more difficult enterprise. On the one hand, it seemed likely that the number of lasers contributed strongly to the intensity of water use for the spaces in which they were used. Results from the previous multivariate regression had demonstrated that this variable contributed very strongly to total water usage on campus. Given the relatively concentrated use that this equipment received, it was likely that this variable would contribute strongly to water consumption rates.

Finally, variables for building space usage, such as the percentage of office space and percentage of classroom space, would contribute rather less explanatory value than the measure of equipment usage but more than the climate measures.

Variable	t-value	Standardized Beta
Cooling degrees	0.226	0.036
Dormitory dummy variable	0.298	0.028
Heating degrees	-0.161	-0.027
Number of lasers	1.040	0.060
Season dummy variable	0.495	0.078
Time	-0.003	0.000

Table 6.4: **The t-values and Standardized Beta Coefficients, Including Main Campus**

Assessing the Model

Selecting all records that showed any figure for gallons per square foot created provided 290 cases. The variables used here included

G = Gallons per Square Foot
C = Percentage of classroom space per building
S = Dummy variable identifying seasonal changes in water use
V = Percentage of lavatory space per building
Z = Number of lasers in a building
O = Percentage of office space per building
D = Dummy variable indicating dormitory use for a building
L = Percentage of laboratory space per building
T = Time variable representing each fiscal year in sequence

The regression equation derived from the sample was

$$\hat{G} = 25.45 - 1.04C + 4.89S + 3.26V + 0.02Z - 0.09O + 2.41D + 3.26L$$

This model had an R^2 value of .090, an adjusted R^2 of .058, and an F-statistic of 2.79 with a probability value of .0026. Coefficients for heating-degree days, cooling-degree days, and time were so close to 0 as not to matter. The t-values appear in

Table 6.4.

Here the signs of the coefficients matched expectations and squared with results from the previous analysis. The magnitudes of the coefficients seemed reasonable in some cases, but not in others, however. For example, one would expect water consumption rates to decline markedly with high percentages of classroom space. The model indicates that it does. Given the association between office and laboratory space, one would expect usage rates to vary somewhat — to go down with office space and up with laboratory space, but not to show great changes in either coefficient. That happens in this model, too. Dorm and lavatory space should show big increases, and do. But one would not expect lasers to contribute as little to water consumption as this model predicts.

Running a regression for the same variables, but excluding records for Main Campus introduced a few changes. The final regression equation was

$$\hat{G} = 24.60 - 1.05C + 5.41S + 3.59V + 0.55Z - 0.12O + 0.99D - 0.08L + 0.05T$$

This model had an R^2 value of .102, an adjusted R^2 of .069, and an F-statistic of 3.08 with a probability value of .0010. Again, coefficients for heating-degree days and cooling-degree days were so small as not to matter for the equation. This time, however, the coefficient for the time variable was large enough to merit inclusion of the variable in the equation. The t-values appear in Table 6.5.

Thus, these showed roughly the same magnitudes for each coefficient. Coefficients for the lasers variable, the dummy variable for dormitory use, and the percentage of laboratory space changed the most.

Variable	t-value	Standardized Beta
Cooling degrees	0.199	0.032
Dormitory dummy variable	0.122	0.012
Heating degrees	-0.128	-0.022
Number of lasers	2.043	0.134
Season dummy variable	0.541	0.085
Time	0.037	0.002

Table 6.5: **The t-values and Standardized Beta Coefficients, Excluding Main Campus**

At this point, time intruded, preventing both more complete analysis of the models as they stood and more extensive modeling itself. The basic goal of beginning to rank factors that contributed to water consumption in an institutional setting was accomplished, however. More work in this area awaits.

Chapter 7

Conclusions

7.1 Summary of the Findings

We conclude the following from this study:

- Overall water usage at MIT is declining with time. This may be due in part to changes in overall space usage, as well as to conservation measures already undertaken by MIT staff.

- Intensity of water use is also generally declining. Excepting North Campus, these declines appear all over the MIT campus.

- Water usage likely increases during the summer in Main Campus and East Campus. This increase may be due in part to sustained laboratory and office activity there together with additional water demand occasioned by the season.

- Water usage per square foot for the whole of Main Campus is only slightly higher than the campus average, not markedly higher. Part of the reason for this, however, is that Main Campus itself represents so much of overall campus water use that it helps to define the campus average.

- Classifying buildings into three different kinds of space usage — dormitory space, office space, and combined laboratory and office space — may be defined to help guage water consumption rates for different buildings on campus.

Each of these spaces has a characteristic average rate of water usage with non-overlapping confidence intervals. Together, these ratios may be used to estimate reasonable levels of consumption for particular buildings and to identify buildings where water is used excessively.

- Useable square feet provides a good general predictor for total water consumption in a building. The count of lasers in a building provides another good predictor for water usage in laboratory space.
- No one factor stands out as a guide for forecasting the semi-annual rate of water usage. Instead, the long-term trend provides a better guide.

7.2 Where Savings are Promising

According to the water usage models, two kinds of places make sensible targets for water conservation — big buildings and dorms. Both sorts of places are easy to identify. Dorms are already a target for water conservation: water-saving shower heads, toilets, and other facilities are being tested on a small scale now. Depending on how the tests go, water conservation should begin soon. Reports on institutional water use from the MWRA indicate that savings of 15% to 20% are routine and payback periods are frequently faster than at first estimated.

The largest buildings on campus, meanwhile, can be found simply by looking at the latest figures on useable space from the OFMS. The fifteen largest buildings on Main Campus in FY91, each of them taking in more than 100,000 square feet, are detailed in Table 6.1.

In some ways, targeting buildings with large square footage may seem too obvious to deserve mention. Nevertheless, note that this result squares with the findings of at least one study of factors that contribute to commercial water use [12]. And, in the absence of a criterion that provides better guidance, it squares with common

Building Number	Name	Useable Square Feet
13	The Vannevar Bush Building	170,836
3	The MacLaurin Building	145,818
4	The MacLaurin Building	145,287
14	Hayden Memorial Library	140,401
36	The Fairchild Building	129,453
56	The Whitaker Building	128,817
10	The MacLaurin Building	127,779
18	Compton Labs	118,845
66	Landau Chemical Engineering Building	116,484
54	Green Building	112,574
2	Unnamed	105,909
16	Dorrance Building	105,502
37	McNair Building	103,861
1	Pierce Engineering Lab	103,417

Table 7.1: **Fifteen Largest Buildings on MIT Main Campus, FY91**

sense. Big buildings house large numbers of people; people use utilities; therefore, big buildings are places where utility use is high and where a conservation program has a chance to be effective.

7.3 Where More Study is Needed

If the Physical Plant Department at MIT is to do a better job at conserving water, it needs first to get a better idea of where water consumption occurs. It cannot do so efficiently until it adds more meters to its facilities in Main Campus. Without added information about consumption to refine the findings of this and other studies, better targeting of water conservation depends on using existing data bases around campus in more sophisticated ways. It will be easier to meter, however, and better for a conservation program in the long run to do so.

Even if MIT's administrators choose to pursue more extensive modeling to forecast water use in the absence of increased metering, they will still find it difficult to evaluate savings due to conservation soundly. As a consequence, plant officials will have trouble knowing when to persist in their conservation strategy, when to change their emphasis, or when to stop investing in conservation altogether.

The data required to focus conservation efforts are available, have been helpful for this study, and will probably be helpful in focusing conservation efforts in the future. Information on building space usage from the Office of Facilities Management Systems is now maintained automatically; therefore it is more precise than it has ever been. Furthermore, OFMS staff pride themselves on the accuracy of their information. Conservation officials may benefit by examining the records that the OFMS maintains, searching for spaces that are likely to create water usage, and using that information to help identify good sites for water savings. The information available through the OFMS is quite extensive and explicit, covering specific kinds of laboratory facilities, shower spaces, darkrooms, and other water using spaces. It should be a ready source of information that can make campus conservation efforts more effective with relatively little investment of time and money.

Information from the Property Office, on the other hand, is of uncertain — and probably uneven — quality. It provides the only centralized source of information about equipment usage on campus, however. The actual value of its records deserves some examination. An audit of campus facilities provides just the instrument for such a test, since it creates a data base that may itself be authenticated and used as a standard for auditing Property Office records.

Once the actual value of these data is ascertained, some easy means of sharing good information needs to be developed. It should not be necessary actually to merge data bases from Physical Plant, the OFMS, and the Property Office together into one large set of files. Such an undertaking would take time that just is not available. It would also probably leave behind an unmanageable mess. It is hard to imagine how anybody except data processing professionals would profit by aggregating these data bases into one entity. All other parties would simply be worse off than they are now.

It seems feasible instead to rely on electronic mail, electronic file transfer, and the ordinary computing tools that now constitute the basic necessities of office life — spreadsheets, data base managers, and word processors — to access, organize, parse, aggregate, and analyze information from a variety of sources. This thesis provides a small example of how this process could work. MIT enjoys a state-of-the-art campus-wide computing environment. Physical Plant can take advantage of these resources at little cost to increase its understanding of campus resource usage patterns and to increase its effectiveness in managing those resources. In that sense, MIT's information systems infrastructure itself provides a tool for getting a better sense of context about utilities usage.

Combining information from various sources would permit each office to maintain the information that it cares most about, but at the same time help round out its understanding of space usage on campus. All parties might benefit from this sort of data sharing, both by increasing the number of people who check and use their information and by learning more about actual operations on campus. Physical Plant staff certainly would profit, as their efforts to regulate and enforce conservation practices would be strengthened. Of course, these techniques will not substitute for actual surveys of MIT facilities, but they may help Physical Plant managers push back the limits of their contextual knowledge. In the long run, this kind of practice may help make conservation planning and implementation more routinely manageable.

This thesis has attempted to put slightly more precision into water resources planning at MIT by creating three measures for representative water usage for various kinds of buildings. These figures are only a starting point, however, for further refinement. In this case, while the average for each kind of space seems to be reasonable, the numbers may give off an aura of precision that is unmerited. Both the averages themselves and the definitions of space usage are as precise as could be managed within the time available; both could use more development.

In line with this effort, more work needs to go into refining definitions of space usage for purposes of water conservation. In particular, a better distinction between kinds of lab space needs to be developed. Some labs, such as those operated by the Department of Urban Studies and Planning, only use electricity. Others that are run within the Biology and Chemistry Departments probably use water more intensively. Each may have a characteristic water consumption rate that will further contribute to estimating water use and setting priorities for water conservation around campus.

In this same vein, the relationship between office and lab space needs more attention. Given the difference in scale between the rates for office water consumption and for combined office and lab water consumption, one would conclude that water tends to be used more intensely in labs than in offices. Greater water savings are likely there and should be pursued. This task will be easier to accomplish when a more exact metric is known.

One key to this work lies in making better use of figures for consumption per useable square foot of space. This ratio provides a standard measure across campus and across institutions that is likely to provide better understanding of water usage over time than usage per person. Many reasons exist for using this alternative form of measurement. First, both space and water usage may be measured consistently; each possesses a stability that is hard to beat. People are more mobile, so their concentration fluctuates from day to day, month to month, and year to year. Comparing usage for the same space over time should therefore be easier and more accurate than comparing usage per person.

Second, based on the work that went into finding population figures for this study, it is easier to get reliable information on space usage than on population. Therefore, usage rates should again be both easier to calculate and more accurate. In fact, it is hard to figure how water usage per person is derived. If this figure is based on building capacities instead of actual populations, it must depend on a measure of space anyway, since maximum capacities must budget a specified amount of space for each person. If not, then what other population measure is available?

Third, as metering becomes more extensive, it should be possible to monitor and regulate water consumption by finer definitions of the kind of space usage that prevails in a particular building and to compare usage in one building against usage in another building. Particular places that show lots of water use should gradually become more obvious, and become regular priorities for water conservation. Better figures for typical residential, commercial, office, and laboratory water consumption should grow simultaneously, allowing for better management of water consumption on campus.

It would be one thing if information about building space were unavailable. At MIT, such is not the case. OFMS has a complete inventory of space usage; they update it twice a year; and they pride themselves on the accuracy of their figures. Running quarterly, semi-annual, or annual reports on utilities usage per useable square foot by building should not be hard, and should contribute greatly to the effectiveness of utilities management on campus.

Two other problems are outside the scope of this study, but deserve mention. First, most articles about resource conservation talk about three tools for implementing these programs — economics, technology, and education. Of these tools, Physical Plant relies primarily on technology and leaves the other two alone.

Regarding economics, MIT pays for its maintenance by exploiting overhead expenses, but these mechanisms provide almost no financial incentives for routine resource conservation. Overhead is almost always considered too high, so increasing it to take account of increased water or electrical costs is never desirable. Furthermore, overhead itself resembles a one-time charge, not an ongoing cost that is tied directly to utilities usage. Improvements no doubt can be made here, but the highly charged nature of overhead accounting makes them unlikely.

Education, on the other hand, is relatively inexpensive and can provide some gains in resource conservation. Physical Plant staff tend to prefer technical solutions to involving itself with students, staff, and faculty on campus. In this area, they might assume a teaching role — a role perfectly suitable in a school.

That said, the link between research and utilities consumption will at some point have to be better articulated and managed. If Physical Plant wants to make its greatest gains in water conservation, it needs to figure out how it can influence or plan around processes in research labs. As Cebon points out, however, traditions within Physical Plant, and within MIT as a whole, prevent the Physical Plant Department from initiating this process on its own. It needs the sanction and guidance of the President's Office if it is to work most effectively at conservation within the Institute. Perhaps MIT can make conservation in research operations *part* of its research mission. Technically, it can be justified; politically, such a policy may bring favorable publicity to the Institute; financially, it may reap large benefits, since water savings translate to savings in other utilities as well.

The question is whether research in processes and basic research can be coordinated successfully. If not, then clearly basic research will take precedence, and conservation efforts will take a lower priority. Given the much-publicized need for American industry to improve its manufacturing processes, however, and the abundance of technical talent in the MIT population, this might be an avenue worth considering for the good of the Institute, its students, and the corporations, agencies, and schools that hire MIT graduates.

7.4 Next Steps in Conservation Planning

It is an emerging tradition in water planning — and in environmental planning generally — to advocate comprehensive planning as the best means to resolving whatever problem lies at hand. In reviewing a number of national water policy studies, Metzger notes,

> Comprehensive, basin-wise management is consistently endorsed by all studies as an essential element in water planning. It seems just as consistently ignored by the governmental institutions whose power is actually at stake. It may have become, in water policy, a "motherhood" objective, which can be invoked repeatedly without fear of implementation. [18, p. 13]

At the risk of falling into the same trap, more *inclusive*, if not comprehensive, planning at least holds out the hope of improving water conservation at the institutional level. This thesis provides one example of an effort to bring together available pieces of information to create a more complete picture of water usage than was available before this year. The benefits are a better understanding of changes in water consumption over the year, better measures of water consumption by building type, and better forecasting tools.

As noted, these measures can use still more refinement. The same general thrust can be used in other areas of conservation, however. For example, water conservation programs at the institutional level could probably benefit from better assessment methods that gave facilities managers more precise figures on water savings due to their water conservation programs. A fuller understanding of which methods performed poorly or well would follow, with the promise for more effective conservation strategies in the future.

Another analysis of particular value would be to identify the savings in *other* utilities that come with water conservation. In this way, the full benefits of water conservation could be accounted for, and the true value for the return on the initial investment in conservation equipment would be known. These figures might be so impressive as to make conservation be seen less as a cost and more as an investment, and therefore make it a much higher priority for institutions.

Finally, this thesis has ignored the financial questions that surround conservation strategies, but those questions deserve serious study at the institutional level. Given that conservation practices that are well-implemented save 15% to 20% — and sometimes more — of total consumption, they should represent an appealing investment to institutional financial managers. Institutional obstacles need to be researched. In addition, money is short these days. Simple financial models that provide for the initial investment in equipment and labor for conservation, accurate evaluation of the program, continuous re-investment in successful conservation programs, and profit remain to be developed and packaged.

Data for Campus-wide Water Consumption

YEAR.PERIOD	GAL	KWH	NO. LASERS	USE SF
1980		42,899,553	235	6,671,645
1980.5	190,622,250	40,585,513	267	6,671,645
1981	265,557,000	46,488,486	290	6,349,272
1981.5	256,002,000	44,552,536	329	6,451,472
1982	317,025,000	48,333,380	352	6,531,165
1982.5	237,600,750	44,375,217	383	6,531,165
1983	315,635,250	47,853,068	403	6,966,506
1983.5	252,435,000	46,887,187	427	6,725,274
1984	280,980,750	51,531,538	474	7,251,674
1984.5	243,831,750	49,940,973	508	7,251,674
1985	260,897,250	55,171,836	524	7,561,632
1985.5	238,573,500	51,113,242	561	7,395,905
1986	280,341,000	54,560,541	589	7,749,374
1986.5		53,218,756	624	7,749,374
1987	306,838,500	60,016,435	636	7,745,926
1987.5	253,554,750	56,893,554	684	7,736,657
1988	307,219,500	60,977,133	686	7,765,025
1988.5	230,253,000	58,048,227	706	7,764,196
1989	303,891,750	62,879,117	741	7,754,401
1989.5	223,656,000	58,482,484	768	7,755,691
1990	278,802,000	61,646,079	778	7,922,936
1990.5	223,503,750	38,772,788	786	7,922,936
1991	280,280,250			7,811,330
1991.5	196,128,750			7,811,330

YEAR.PERIOD	OFF SF	CLS SF	LAB SF	PVT LAV
1980	1,201,937	162,326	1,137,553	6,578
1980.5	1,201,937	162,326	1,137,553	6,578
1981	1,183,958	153,276	1,056,668	22,519
1981.5	1,186,618	156,413	1,087,984	14,545
1982	1,204,984	153,394	1,041,422	30,806
1982.5	1,204,984	153,394	1,041,422	30,806
1983	1,301,692	166,294	1,044,192	40,643
1983.5	1,247,641	158,219	1,034,764	35,723
1984	1,366,726	179,545	1,064,345	45,560
1984.5	1,366,726	179,545	1,064,345	45,560
1985	1,413,994	187,163	1,100,604	54,206
1985.5	1,386,459	183,353	1,078,969	49,881
1986	1,449,826	190,971	1,130,601	58,527
1986.5	1,449,826	190,971	1,130,601	58,527
1987	1,438,231	188,066	1,112,970	58,391
1987.5	1,439,876	189,518	1,117,609	58,460
1988	1,438,786	186,489	1,111,825	58,330
1988.5	1,438,447	186,613	1,112,055	58,324
1989	1,461,438	179,155	1,120,151	56,042
1989.5	1,449,213	182,821	1,114,126	57,190
1990	1,497,119	175,487	1,126,415	55,092
1990.5	1,497,119	175,487	1,126,415	55,092
1991	1,575,622	171,342	1,123,187	55,103
1991.5	1,575,622	171,342	1,123,187	55,103

YEAR.PERIOD	M LAV	F LAV	TOT LAV
1980	0	0	0
1980.5	0	0	3,765
1981	51,011	0	53,303
1981.5	25,503	0	29,037
1982	79,697	0	81,822
1982.5	79,697	0	83,596
1983	81,049	0	82,777
1983.5	80,118	0	83,526
1984	82,080	0	84,030
1984.5	82,080	0	85,910
1985	84,275	0	86,165
1985.5	83,128	0	86,784
1986	85,529	4,635	92,156
1986.5	85,529	4,635	90,164
1987	84,203	536	86,796
1987.5	84,814	268	88,954
1988	83,417	1,073	86,413
1988.5	83,694	804	88,235
1989	59,112	25,133	86,304
1989.5	71,218	13,104	87,884
1990	47,099	37,233	86,716
1990.5	47,099	37,233	87,722
1991	47,372	37,530	86,438
1991.5	47,372	37,530	88,090

YEAR.PERIOD	H DEG	C DEG	PRECIP
1980			
1980.5	3,765	132	16.7
1981	2,292	784	12.69
1981.5	3,534	252	14.18
1982	2,125	598	21.53
1982.5	3,899	82	28.72
1983	1,728	567	15.89
1983.5	3,408	225	30.62
1984	1,950	937	22.98
1984.5	3,830	241	33.2
1985	1,890	683	17.04
1985.5	3,656	107	14.16
1986	1,992	545	22.43
1986.5			
1987	2,057	466	24.02
1987.5	3,872	135	26.1
1988	1,923	488	19.38
1988.5	3,737	204	15.57
1989	2,059	699	19.21
1989.5	3,562	172	16.15
1990	2,384	551	26.27
1990.5	3,390	128	22.25
1991	1,536	648	24.25
1991.5	3,188	271	17.8

Data for Water Consumption by Geographic Area

Central Campus

YEAR.PERIOD	PFX	GAL	H_DEG	C_DEG	PRECIP
1980.5	C	109,620,750	3,765	132	16.70
1981	C	128,949,000	2,292	784	12.69
1981.5	C	121,848,750	3,534	252	14.18
1982	C	165,483,000	2,125	598	21.53
1982.5	C	120,465,000	3,899	82	28.72
1983	C	159,383,250	1,728	567	15.89
1983.5	C	124,587,000	3,408	225	30.62
1984	C	124,290,750	1,950	937	22.98
1984.5	C	97,091,250	3,830	241	33.20
1985	C	107,475,000	1,890	683	17.04
1985.5	C	97,810,500	3,656	107	14.16
1986	C	142,956,750	1,992	545	22.43
1987	C	154,874,250	2,057	466	24.02
1987.5	C	121,769,250	3,872	135	26.10
1988	C	144,260,250	1,923	488	19.38
1988.5	C	93,302,250	3,737	204	15.57
1989	C	129,727,500	2,059	699	19.21
1989.5	C	97,621,500	3,562	172	16.15
1990	C	129,561,750	2,384	551	26.27
1990.5	C	100,561,500	3,390	128	22.25
1991	C	131,715,000	1,536	648	24.25
1991.5	C	77,726,250	3,188	271	17.80

Central Campus

YEAR.PERIOD	KWH	USE_SF	OFF_SF	CLS_SF
1980.5	28,050,215	3,346,726	745,749	122,655
1981	32,369,144	3,298,637	752,474	124,907
1981.5	31,731,172	3,318,671	748,002	123,782
1982	31,927,594	3,286,649	758,859	126,034
1982.5	28,539,663	3,286,649	758,859	126,034
1983	29,327,743	3,274,246	746,246	125,904
1983.5	29,517,763	3,276,429	751,595	125,967
1984	28,957,195	3,302,699	746,292	131,015
1984.5	29,787,516	3,302,699	746,292	131,015
1985	30,544,175	3,305,649	761,250	136,837
1985.5	30,197,099	3,300,081	752,663	133,925
1986	30,940,384	3,319,421	772,049	139,747
1987	35,267,995	3,317,399	763,763	136,993
1987.5	34,072,360	3,314,317	766,798	138,369
1988	34,678,413	3,329,358	762,860	135,491
1988.5	35,215,532	3,328,529	762,521	135,615
1989	36,469,773	3,299,093	766,195	132,707
1989.5	35,446,474	3,310,205	763,633	134,097
1990	32,848,965	3,416,200	768,763	131,313
1990.5	20,826,072	3,416,200	768,763	131,313
1991	0	3,309,727	792,181	127,557
1991.5	0	3,309,727	792,181	127,557

Central Campus

YEAR.PERIOD	LAB_SF	PVT_LAV	M_LAV	F_LAV
1980.5	835,927	2,560	0	0
1981	809,184	6,655	30,599	0
1981.5	821,534	4,606	15,299	0
1982	798,610	8,701	46,001	0
1982.5	798,610	8,701	46,001	0
1983	768,478	8,743	44,682	0
1983.5	782,655	8,722	45,291	0
1984	759,934	8,764	44,178	0
1984.5	759,934	8,764	44,178	0
1985	773,614	8,705	44,813	0
1985.5	765,817	8,733	44,444	0
1986	785,135	8,674	45,285	0
1987	774,128	8,722	44,587	536
1987.5	777,771	8,699	44,885	268
1988	773,976	8,753	44,116	1,073
1988.5	774,206	8,747	44,393	804
1989	757,961	8,694	31,095	13,029
1989.5	764,104	8,726	37,556	7,049
1990	751,810	8,667	24,638	19,005
1990.5	751,810	8,667	24,638	19,005
1991	747,850	8,667	24,638	18,772
1991.5	747,850	8,667	24,638	18,772

Central Campus

YEAR.PERIOD	NO_LASERS	BLDG_AGE
1980.5	214	41.98
1981	232	42.44
1981.5	267	42.95
1982	282	43.41
1982.5	307	43.89
1983	327	44.41
1983.5	344	44.89
1984	371	45.16
1984.5	402	45.65
1985	414	46.17
1985.5	451	46.66
1986	479	47.17
1987	517	48.43
1987.5	563	48.67
1988	560	49.19
1988.5	580	49.69
1989	613	50.10
1989.5	637	50.89
1990	646	51.06
1990.5	647	51.56
1991	0	0.00
1991.5	0	0.00

East Campus

YEAR.PERIOD	PFX	GAL	H_DEG	C_DEG
1980.5	E	32,820,000	3,765	132
1981	E	50,705,250	2,292	784
1981.5	E	45,006,750	3,534	252
1982	E	46,849,500	2,125	598
1982.5	E	37,767,750	3,899	82
1983	E	61,446,000	1,728	567
1983.5	E	46,407,750	3,408	225
1984	E	52,791,750	1,950	937
1984.5	E	48,784,500	3,830	241
1985	E	49,524,750	1,890	683
1985.5	E	46,436,250	3,656	107
1986	E	28,502,250	1,992	545
1987	E	42,278,250	2,057	466
1987.5	E	32,131,500	3,872	135
1988	E	38,379,000	1,923	488
1988.5	E	31,437,750	3,737	204
1989	E	32,301,000	2,059	699
1989.5	E	23,033,250	3,562	172
1990	E	40,499,250	2,384	551
1990.5	E	26,970,750	3,390	128
1991	E	34,927,500	1,536	648
1991.5	E	27,238,500	3,188	271

East Campus

YEAR.PERIOD	PRECIP	KWH	USE_SF	OFF_SF
1980.5	16.70	4,559,077	1,162,091	278,538
1981	12.69	5,669,466	1,033,604	254,046
1981.5	14.18	4,731,147	1,078,206	264,225
1982	21.53	6,344,313	1,014,721	247,765
1982.5	28.72	5,364,131	1,014,721	247,765
1983	15.89	7,752,422	1,181,790	337,454
1983.5	30.62	5,839,499	1,085,392	290,660
1984	22.98	8,621,998	1,278,178	384,248
1984.5	33.20	5,631,968	1,278,178	384,248
1985	17.04	8,004,647	1,377,176	405,752
1985.5	14.16	5,333,279	1,327,678	394,999
1986	22.43	7,801,835	1,426,819	416,646
1987	24.02	8,247,220	1,441,996	419,733
1987.5	26.10	6,376,718	1,434,338	418,118
1988	19.38	9,239,983	1,449,658	421,348
1988.5	15.57	6,705,897	1,449,658	421,348
1989	19.21	10,284,410	1,448,868	430,023
1989.5	16.15	7,240,576	1,449,264	425,682
1990	26.27	11,550,353	1,490,083	457,816
1990.5	22.25	7,673,302	1,490,083	457,816
1991	24.25	0	1,488,196	471,793
1991.5	17.80	0	1,488,196	471,793

East Campus

YEAR.PERIOD	CLS_SF	LAB_SF	LASER/LAB SF	PVT_LAV
1980.5	23,021	105,933	0.004%	1,699
1981	20,815	72,323	0.006%	3,136
1981.5	20,527	83,576	0.005%	2,416
1982	24,352	70,270	0.006%	3,853
1982.5	24,352	70,270	0.006%	3,853
1983	26,347	96,558	0.004%	4,658
1983.5	23,726	78,813	0.006%	4,253
1984	28,969	114,301	0.008%	5,058
1984.5	28,969	114,301	0.008%	5,058
1985	30,056	122,186	0.008%	5,041
1985.5	29,513	118,244	0.008%	5,050
1986	30,600	126,129	0.008%	5,033
1987	30,391	129,981	0.012%	5,054
1987.5	30,495	128,054	0.012%	5,043
1988	30,286	131,906	0.014%	5,064
1988.5	30,286	131,906	0.015%	5,064
1989	29,484	132,987	0.017%	5,515
1989.5	29,886	132,449	0.018%	5,290
1990	29,084	133,772	0.018%	5,931
1990.5	29,084	133,772	0.022%	5,931
1991	27,744	133,360	0.000%	5,842
1991.5	27,744	133,360	0.000%	5,842

East Campus

YEAR.PERIOD	M_LAV	F_LAV	NO_LASERS	BLDG_AGE
1980.5	0	0	4	33.79
1981	11,379	0	4	35.76
1981.5	5,688	0	4	35.49
1982	17,471	0	4	37.59
1982.5	17,471	0	4	38.09
1983	18,074	0	4	34.01
1983.5	17,570	0	5	36.59
1984	18,577	0	9	33.24
1984.5	18,577	0	9	33.74
1985	19,733	0	10	33.16
1985.5	19,155	0	10	34.18
1986	20,311	0	10	33.68
1987	20,311	0	15	34.33
1987.5	20,311	0	16	35.00
1988	20,311	0	19	35.16
1988.5	20,311	0	20	35.66
1989	13,819	6,434	22	36.15
1989.5	17,067	3,221	24	36.65
1990	10,658	9,724	24	38.15
1990.5	10,658	9,724	29	38.65
1991	10,697	10,257	0	0.00
1991.5	10,697	10,257	0	0.00

North Campus

YEAR.PERIOD	PFX	GAL	H_DEG	C_DEG
1980.5	N	852,750	3,765	132
1981	N	3,322,500	2,292	784
1981.5	N	5,052,750	3,534	252
1982	N	15,450,000	2,125	598
1982.5	N	6,813,000	3,899	82
1983	N	13,451,250	1,728	567
1983.5	N	9,848,250	3,408	225
1984	N	25,689,000	1,950	937
1984.5	N	13,491,750	3,830	241
1985	N	20,547,000	1,890	683
1985.5	N	11,565,000	3,656	107
1986	N	24,847,500	1,992	545
1987	N	26,010,000	2,057	466
1987.5	N	19,308,000	3,872	135
1988	N	40,592,250	1,923	488
1988.5	N	36,471,750	3,737	204
1989	N	59,198,250	2,059	699
1989.5	N	31,149,000	3,562	172
1990	N	43,403,250	2,384	551
1990.5	N	29,778,000	3,390	128
1991	N	42,708,000	1,536	648
1991.5	N	24,699,000	3,188	271

North Campus

YEAR.PERIOD	PRECIP	KWH	USE_SF	OFF_SF
1980.5	16.70	1,968,920	342,733	72,061
1981	12.69	2,208,054	309,654	69,056
1981.5	14.18	1,905,354	319,502	67,767
1982	21.53	2,310,747	313,163	75,930
1982.5	28.72	2,572,742	313,163	75,930
1983	15.89	2,712,737	339,116	73,288
1983.5	30.62	3,053,760	319,459	71,817
1984	22.98	3,449,505	372,081	80,343
1984.5	33.20	3,437,853	372,081	80,343
1985	17.04	4,116,135	431,607	83,180
1985.5	14.16	3,894,234	395,188	78,970
1986	22.43	4,015,619	481,692	93,335
1987	24.02	4,345,960	469,025	91,714
1987.5	26.10	4,441,283	468,524	89,552
1988	19.38	4,517,793	469,524	93,875
1988.5	15.57	4,336,218	469,524	93,875
1989	19.21	4,380,690	475,567	97,559
1989.5	16.15	4,284,831	472,544	95,716
1990	26.27	4,150,054	478,587	99,400
1990.5	22.25	3,750,910	478,587	99,400
1991	24.25	0	479,719	101,100
1991.5	17.80	0	479,719	101,100

North Campus

YEAR.PERIOD	CLS_SF	LAB_SF	PVT_LAV	M_LAV
1980.5	0	36,198	0	0
1981	0	32,471	60	1,077
1981.5	0	31,783	30	538
1982	0	38,256	90	1,615
1982.5	0	38,256	90	1,615
1983	1,539	35,004	198	2,055
1983.5	770	34,079	144	1,835
1984	2,309	41,027	252	2,275
1984.5	2,309	41,027	252	2,275
1985	2,309	35,254	252	2,275
1985.5	2,309	35,592	252	2,275
1986	2,309	39,554	252	2,275
1987	2,682	32,584	241	2,216
1987.5	2,496	33,751	247	2,245
1988	2,869	31,416	236	2,186
1988.5	2,869	31,416	236	2,186
1989	1,506	39,118	255	1,711
1989.5	2,188	35,268	245	1,949
1990	825	42,970	264	1,474
1990.5	825	42,970	264	1,474
1991	1,899	43,903	264	1,533
1991.5	1,899	43,903	264	1,533

North Campus

YEAR.PERIOD	F_LAV	NO_LASERS	BLDG_AGE
1980.5	0	1	63.45
1981	0	1	63.52
1981.5	0	2	64.24
1982	0	3	64.28
1982.5	0	4	64.78
1983	0	4	60.42
1983.5	0	4	63.18
1984	0	18	59.43
1984.5	0	21	59.93
1985	0	21	64.37
1985.5	0	21	63.07
1986	4,635	21	66.91
1987	0	27	67.89
1987.5	0	27	68.40
1988	0	27	68.88
1988.5	0	27	69.38
1989	755	27	70.26
1989.5	376	27	70.57
1990	1,131	27	71.45
1990.5	1,131	32	71.95
1991	1,131	0	0.00
1991.5	1,131	0	0.00

Northwest Campus

YEAR.PERIOD	PFX	GAL	H_DEG	C_DEG
1980.5	X	2,028,750	3,765	132
1981	X	14,513,250	2,292	784
1981.5	X	18,657,000	3,534	252
1982	X	22,235,250	2,125	598
1982.5	X	18,299,250	3,899	82
1983	X	20,041,500	1,728	567
1983.5	X	21,414,750	3,408	225
1984	X	21,640,500	1,950	937
1984.5	X	19,591,500	3,830	241
1985	X	21,021,750	1,890	683
1985.5	X	21,418,500	3,656	107
1986	X	23,130,000	1,992	545
1987	X	23,745,750	2,057	466
1987.5	X	16,470,000	3,872	135
1988	X	19,331,250	1,923	488
1988.5	X	14,929,500	3,737	204
1989	X	15,921,750	2,059	699
1989.5	X	13,530,000	3,562	172
1990	X	12,970,500	2,384	551
1990.5	X	13,568,250	3,390	128
1991	X	15,117,000	1,536	648
1991.5	X	13,925,250	3,188	271

Northwest Campus

YEAR.PERIOD	PRECIP	KWH	USE_SF	OFF_SF
1980.5	16.70	2,700,940	324,027	50,154
1981	12.69	3,090,936	280,435	50,360
1981.5	14.18	2,844,488	273,586	49,895
1982	21.53	4,289,628	393,678	55,595
1982.5	28.72	3,949,600	393,678	55,595
1983	15.89	4,451,444	449,753	66,036
1983.5	30.62	4,125,830	421,717	60,817
1984	22.98	5,590,166	477,792	71,258
1984.5	33.20	5,201,349	477,792	71,258
1985	17.04	6,331,501	522,540	82,736
1985.5	14.16	5,522,359	500,166	76,997
1986	22.43	5,840,066	544,914	88,475
1987	24.02	6,575,129	541,650	85,886
1987.5	26.10	5,788,839	543,284	87,179
1988	19.38	6,392,809	540,020	84,590
1988.5	15.57	5,692,027	540,020	84,590
1989	19.21	6,081,683	536,932	84,037
1989.5	16.15	5,778,008	538,475	84,313
1990	26.27	6,133,793	535,387	83,760
1990.5	22.25	6,059,860	535,387	83,760
1991	24.25	0	535,479	85,519
1991.5	17.80	0	535,479	85,519

Northwest Campus

YEAR.PERIOD	CLS_SF	LAB_SF	PVT_LAV	M_LAV
1980.5	1,150	117,926	207	0
1981	1,167	105,912	207	2,448
1981.5	1,159	111,919	207	1,225
1982	1,176	99,905	207	5,255
1982.5	1,176	99,905	207	5,255
1983	2,129	120,826	963	5,876
1983.5	1,653	110,366	585	5,565
1984	2,606	131,287	1,341	6,186
1984.5	2,606	131,287	1,341	6,186
1985	2,935	154,035	1,203	6,610
1985.5	2,771	142,660	1,272	6,398
1986	3,100	165,408	1,134	6,822
1987	3,100	162,894	1,134	6,822
1987.5	3,100	164,153	1,134	6,822
1988	3,100	161,639	1,134	6,822
1988.5	3,100	161,639	1,134	6,822
1989	2,530	176,936	1,091	5,289
1989.5	2,814	169,287	1,112	6,054
1990	2,244	184,584	1,069	4,521
1990.5	2,244	184,584	1,069	4,521
1991	2,244	185,778	1,069	4,555
1991.5	2,244	185,778	1,069	4,555

Northwest Campus

YEAR.PERIOD	F_LAV	NO_LASERS	BLDG_AGE
1980.5	0	45	46.48
1981	0	50	37.86
1981.5	0	53	39.24
1982	0	60	45.28
1982.5	0	65	45.78
1983	0	65	42.03
1983.5	0	70	44.51
1984	0	72	41.29
1984.5	0	72	41.79
1985	0	75	43.16
1985.5	0	75	43.23
1986	0	75	44.53
1987	0	73	45.74
1987.5	0	73	46.13
1988	0	75	46.85
1988.5	0	75	47.35
1989	1,627	75	47.94
1989.5	814	76	48.39
1990	2,441	77	48.98
1990.5	2,441	75	49.48
1991	2,441	0	0.00
1991.5	2,441	0	0.00

West Campus

YEAR.PERIOD	PFX	GAL	H_DEG	C_DEG
1980.5	W	42,704,250	3,765	132
1981	W	63,129,750	2,292	784
1981.5	W	62,182,500	3,534	252
1982	W	62,796,750	2,125	598
1982.5	W	51,381,000	3,899	82
1983	W	58,422,000	1,728	567
1983.5	W	47,892,750	3,408	225
1984	W	53,741,250	1,950	937
1984.5	W	62,511,750	3,830	241
1985	W	59,768,250	1,890	683
1985.5	W	59,062,500	3,656	107
1986	W	57,967,500	1,992	545
1987	W	58,554,750	2,057	466
1987.5	W	63,876,000	3,872	135
1988	W	64,656,750	1,923	488
1988.5	W	54,111,750	3,737	204
1989	W	66,743,250	2,059	699
1989.5	W	58,322,250	3,562	172
1990	W	52,367,250	2,384	551
1990.5	W	52,625,250	3,390	128
1991	W	55,812,750	1,536	648
1991.5	W	52,539,750	3,188	271

West Campus

YEAR.PERIOD	PRECIP	KWH	USE_SF	OFF_SF
1980.5	16.70	3,046,853	1,496,068	55,435
1981	12.69	2,891,424	1,426,942	58,022
1981.5	14.18	3,089,444	1,461,507	56,729
1982	21.53	3,188,253	1,522,954	66,835
1982.5	28.72	3,697,587	1,522,954	66,835
1983	15.89	3,361,139	1,721,601	78,668
1983.5	30.62	4,094,807	1,622,277	72,752
1984	22.98	4,645,551	1,820,924	84,585
1984.5	33.20	5,626,433	1,820,924	84,585
1985	17.04	5,896,083	1,924,660	81,076
1985.5	14.16	5,913,269	1,872,792	82,830
1986	22.43	5,689,260	1,976,528	79,321
1987	24.02	5,323,530	1,975,856	77,135
1987.5	26.10	5,736,677	1,976,194	78,229
1988	19.38	5,814,285	1,976,465	76,113
1988.5	15.57	5,873,300	1,976,465	76,113
1989	19.21	5,396,478	1,993,941	83,624
1989.5	16.15	5,471,585	1,985,203	79,869
1990	26.27	6,677,580	2,002,679	87,380
1990.5	22.25	247,886	2,002,679	87,380
1991	24.25	0	1,998,209	125,029
1991.5	17.80	0	1,998,209	125,029

West Campus

YEAR.PERIOD	CLS_SF	LAB_SF	PVT_LAV	M_LAV
1980.5	15,500	41,569	2,112	0
1981	6,387	36,778	12,461	5,508
1981.5	10,945	39,172	7,286	2,753
1982	1,832	34,381	17,955	9,355
1982.5	1,832	34,381	17,955	9,355
1983	10,375	23,326	26,081	10,362
1983.5	6,103	28,851	22,019	9,857
1984	14,646	17,796	30,145	10,864
1984.5	14,646	17,796	30,145	10,864
1985	15,026	15,515	39,005	10,844
1985.5	14,835	16,656	34,574	10,856
1986	15,215	14,375	43,434	10,836
1987	14,900	13,383	43,240	10,267
1987.5	15,058	13,880	43,337	10,551
1988	14,743	12,888	43,143	9,982
1988.5	14,743	12,888	43,143	9,982
1989	12,928	13,149	40,487	7,198
1989.5	13,836	13,018	41,817	8,592
1990	12,021	13,279	39,161	5,808
1990.5	12,021	13,279	39,161	5,808
1991	11,898	12,296	39,261	5,949
1991.5	11,898	12,296	39,261	5,949

West Campus

YEAR.PERIOD	F_LAV	NO_LASERS	BLDG_AGE
1980.5	0	2	35.78
1981	0	2	36.51
1981.5	0	2	36.89
1982	0	2	34.93
1982.5	0	2	35.42
1983	0	2	33.64
1983.5	0	2	35.03
1984	0	2	33.84
1984.5	0	2	34.34
1985	0	2	37.60
1985.5	0	2	36.75
1986	0	2	39.88
1987	0	2	40.88
1987.5	0	2	41.37
1988	0	2	41.87
1988.5	0	1	42.37
1989	3,288	1	43.35
1989.5	1,644	1	43.61
1990	4,932	1	44.59
1990.5	4,932	1	45.09
1991	4,929	0	0.00
1991.5	4,929	0	0.00

Data for Water Consumption by Building

Note: Due to the size of this data set, this appendix only lists data for FY90.

1990, Period 1

BLDG_NO	TIME	DUMSEAS	PERIOD	DUMMAIN
33	11	1	1	0
35	11	1	1	0
41	11	1	1	0
45	11	1	1	0
48	11	1	1	0
51	11	1	1	0
E10	11	1	1	0
E15	11	1	1	0
E17	11	1	1	0
E2	11	1	1	0
E20	11	1	1	0
E32	11	1	1	0
E40	11	1	1	0
E51	11	1	1	0
MC	11	1	1	1
N42	11	1	1	0
N51	11	1	1	0
N57	11	1	1	0
NW13	11	1	1	0
NW14	11	1	1	0
NW16	11	1	1	0
NW17	11	1	1	0
NW21	11	1	1	0
NW30	11	1	1	0
W11	11	1	1	0
W31	11	1	1	0
W45	11	1	1	0
W59	11	1	1	0
W61	11	1	1	0
W70	11	1	1	0
W71	11	1	1	0
W74	11	1	1	0
W84	11	1	1	0
W91	11	1	1	0

1990, Period 1

BLDG_NO	USE_SF	OFF_SF	CLS_SF	LAB_SF
33	44,109	14,584	2,842	9,660
35	60,051	22,058	757	16,503
41	34,161	5,841	0	13,339
45	12,353	4,257	0	4,059
48	43,455	9,455	2,704	17,620
51	5,361	447	919	0
E10	32,042	9,832	716	7,258
E15	105,313	31,888	2,683	20,348
E17	79,744	11,991	0	37,653
E2	71,860	4,581	0	712
E20	10,472	1,079	0	2,446
E32	12,297	8,556	340	0
E40	96,119	57,449	0	0
E51	50,180	14,550	14,369	0
MC	3,364,169	712,121	124,091	690,629
N42	29,797	5,126	0	3,120
N51	39,508	5,399	0	11,422
N57	44,826	1,394	0	0
NW13	57,187	7,495	0	27,263
NW14	134,959	28,895	1,079	68,688
NW16	46,657	17,745	0	2,294
NW17	40,280	14,217	9	9,497
NW21	77,718	7,377	0	45,029
NW30	83,802	388	0	0
W11	11,652	1,607	0	5,951
W31	62,506	7,938	123	0
W45	182,997	338	0	0
W59	32,352	6,097	0	327
W61	139,465	12,265	0	435
W70	100,010	338	0	0
W71	114,525	748	0	0
W74	1,322	54	0	810
W84	135,585	195	0	55
W91	31,953	7,546	0	0

1990, Period 1

BLDG_NO	PVT_LAV	M_LAV	F_LAV	TOTLAV
33	0	609	0	609
35	0	1,104	553	1,657
41	67	471	329	867
45	76	44	40	160
48	0	486	221	707
51	0	16	16	32
E10	30	488	495	1,013
E15	31	817	815	1,663
E17	179	735	758	1,672
E2	3,649	102	0	3,751
E20	66	59	0	125
E32	0	66	55	121
E40	0	723	632	1,355
E51	0	615	521	1,136
MC	8,591	21,908	17,846	48,345
N42	0	278	250	528
N51	0	661	463	1,124
N57	193	0	0	193
NW13	0	583	0	583
NW14	0	1,065	872	1,937
NW16	0	450	376	826
NW17	0	414	99	513
NW21	0	322	291	613
NW30	0	1,279	459	1,738
W11	0	30	30	60
W31	123	746	672	1,541
W45	0	0	0	0
W59	228	179	184	591
W61	6,045	261	201	6,507
W70	5,653	0	0	5,653
W71	1,745	158	656	2,559
W74	20	0	0	20
W84	0	57	0	57
W91	0	481	126	607

1990, Period 1

BLDG_NO	DUMDORM	USE	TYPE	GALSQFT
33	0	R	OTR	2.31
35	0	R	OTR	47.98
41	0	R	OTR	5.66
45	0	R	OTR	48.94
48	0	R	OTR	13.62
51	0	R	SRA	13.99
E10	0	MNS	OTR	51.17
E15	0	R	OTR	1.67
E17	0	R	OTR	78.51
E2	1	R	HSG	38.30
E20	0	R	OTR	2.86
E32	0	MNS	OTR	11.77
E40	0	MNS	OTR	55.40
E51	0	R	OTR	4.95
MC	0	GEN	MGL	37.19
N42	0	R	OTR	91.97
N51	0	RA	OTR	64.03
N57	0	R	OTR	0.17
NW13	0	R	OTR	2.07
NW14	0	R	OTR	47.75
NW16	0	R	OTR	7.80
NW17	0	R	OTR	1.40
NW21	0	R	OTR	25.74
NW30	0			0.00
W11	0	R	OTR	21.56
W31	0	R	SRA	38.80
W45	0	ANS	SRA	9.82
W59	0	R	OTR	13.82
W61	1	R	HSG	23.43
W70	1	MNS	HSG	33.62
W71	1	ANS	SRA	26.21
W74	0	R	OTR	0.00
W84	1	R	HSG	54.75
W91	0	R	OTR	178.18

1990, Period 1

BLDG_NO	GAL	H_DEG	C_DEG	PRECIP
33	102,000	2,384	551	26.27
35	2,881,500	2,384	551	26.27
41	193,500	2,384	551	26.27
45	604,500	2,384	551	26.27
48	591,750	2,384	551	26.27
51	75,000	2,384	551	26.27
E10	1,639,500	2,384	551	26.27
E15	175,500	2,384	551	26.27
E17	6,261,000	2,384	551	26.27
E2	2,752,500	2,384	551	26.27
E20	30,000	2,384	551	26.27
E32	144,750	2,384	551	26.27
E40	5,325,000	2,384	551	26.27
E51	248,250	2,384	551	26.27
MC	125,113,500	2,384	551	26.27
N42	2,740,500	2,384	551	26.27
N51	2,529,750	2,384	551	26.27
N57	7,500	2,384	551	26.27
NW13	118,500	2,384	551	26.27
NW14	6,444,000	2,384	551	26.27
NW16	363,750	2,384	551	26.27
NW17	56,250	2,384	551	26.27
NW21	2,000,250	2,384	551	26.27
NW30	0	0	0	0
W11	251,250	2,384	551	26.27
W31	2,425,500	2,384	551	26.27
W45	1,797,750	2,384	551	26.27
W59	447,000	2,384	551	26.27
W61	3,267,750	2,384	551	26.27
W70	3,362,250	2,384	551	26.27
W71	3,001,500	2,384	551	26.27
W74	0	2,384	551	26.27
W84	7,422,750	2,384	551	26.27
W91	5,693,250	2,384	551	26.27

1990, Period 1

BLDG_NO	KWH	NO_LASER	BLDG_AGE	PCTOFF
33	260,325	2	66.80	33.06
35	580,156	7	43.40	36.73
41	205,789	2	79.10	17.10
45	393,360	0	17.00	34.46
48	20,327	6	45.00	21.76
51	2,481	0	58.00	8.34
E10	520,464	1	81.10	30.68
E15	1,215,360	18	12.00	30.28
E17	3,470,460	0	30.00	15.04
E2	128,400	0	80.60	6.37
E20	1,029	1	74.10	10.30
E32	125,040	0	71.00	69.58
E40	2,002,560	0	25.00	59.77
E51	1,494	0	50.00	29.00
MC	31,482,254	629	50.76	21.17
N42	168,320	0	87.10	17.20
N51	392,820	0	70.00	13.67
N57	74,800	0	30.00	3.11
NW13	738,288	6	81.10	13.11
NW14	3,011,298	40	32.10	21.41
NW16	417,000	5	10.60	38.03
NW17	476,280	7	90.10	35.30
NW21	1,386,960	18	13.70	9.49
NW30	103,967	1	90.10	0.46
W11	58,550	1	27.00	13.79
W31	247,928	0	90.10	12.70
W45	215,761	0	90.10	0.18
W59	83,700	0	15.00	18.85
W61	487,000	0	25.50	8.79
W70	598,800	0	19.60	0.34
W71	594,560	0	14.30	0.65
W74	3,378	0	17.30	4.08
W84	635,000	0	23.20	0.14
W91	2,803,200	0	47.00	23.62

1990, Period 1

BLDG_NO	PCTCLS	PCTLAB	PCTLAV	BLD_TYPE
33	6.44	21.90	1.38	2
35	1.26	27.48	2.76	2
41	0.00	39.05	2.54	2
45	0.00	32.86	1.30	2
48	6.22	40.55	1.63	2
51	17.14	0.00	0.60	
E10	2.23	22.65	3.16	2
E15	2.55	19.32	1.58	2
E17	0.00	47.22	2.10	2
E2	0.00	0.99	5.22	1
E20	0.00	23.36	1.19	2
E32	2.76	0.00	0.98	3
E40	0.00	0.00	1.41	3
E51	28.63	0.00	2.26	3
MC	3.69	20.53	1.44	2
N42	0.00	10.47	1.77	2
N51	0.00	28.91	2.84	2
N57	0.00	0.00	0.43	2
NW13	0.00	47.67	1.02	2
NW14	0.80	50.90	1.44	2
NW16	0.00	4.92	1.77	3
NW17	0.02	23.58	1.27	2
NW21	0.00	57.94	0.79	2
NW30	0.00	0.00	2.07	2
W11	0.00	51.07	0.51	2
W31	0.20	0.00	2.47	2
W45	0.00	0.00	0.00	2
W59	0.00	1.01	1.83	2
W61	0.00	0.31	4.67	1
W70	0.00	0.00	5.65	1
W71	0.00	0.00	2.23	1
W74	0.00	61.27	1.51	2
W84	0.00	0.04	0.04	1
W91	0.00	0.00	1.90	3

1990, Period 2

BLDG_NO	TIME	DUMSEAS	PERIOD	DUMMAIN
33	11	0	2	0
35	11	0	2	0
41	11	0	2	0
45	11	0	2	0
48	11	0	2	0
51	11	0	2	0
E10	11	0	2	0
E15	11	0	2	0
E17	11	0	2	0
E2	11	0	2	0
E20	11	0	2	0
E32	11	0	2	0
E40	11	0	2	0
E51	11	0	2	0
MC	11	0	2	1
N42	11	0	2	0
N51	11	0	2	0
N57	11	0	2	0
NW13	11	0	2	0
NW14	11	0	2	0
NW16	11	0	2	0
NW17	11	0	2	0
NW21	11	0	2	0
NW30	11	0	2	0
W11	11	0	2	0
W31	11	0	2	0
W45	11	0	2	0
W59	11	0	2	0
W61	11	0	2	0
W70	11	0	2	0
W71	11	0	2	0
W74	11	0	2	0
W84	11	0	2	0
W91	11	0	2	0

1990, Period 2

BLDG_NO	USE_SF	OFF_SF	CLS_SF	LAB_SF
33	44,109	14,584	2,842	9,660
35	60,051	22,058	757	16,503
41	34,161	5,841	0	13,339
45	12,353	4,257	0	4,059
48	43,455	9,455	2,704	17,620
51	5,361	447	919	0
E10	32,042	9,832	716	7,258
E15	105,313	31,888	2,683	20,348
E17	79,744	11,991	0	37,653
E2	71,860	4,581	0	712
E20	10,472	1,079	0	2,446
E32	12,297	8,556	340	0
E40	96,119	57,449	0	0
E51	50,180	14,550	14,369	0
MC	3,364,169	712,121	124,091	690,629
N42	29,797	5,126	0	3,120
N51	39,508	5,399	0	11,422
N57	44,826	1,394	0	0
NW13	57,187	7,495	0	27,263
NW14	134,959	28,895	1,079	68,688
NW16	46,657	17,745	0	2,294
NW17	40,280	14,217	9	9,497
NW21	77,718	7,377	0	45,029
NW30	83,802	388	0	0
W11	11,652	1,607	0	5,951
W31	62,506	7,938	123	0
W45	182,997	338	0	0
W59	32,352	6,097	0	327
W61	139,465	12,265	0	435
W70	100,010	338	0	0
W71	114,525	748	0	0
W74	1,322	54	0	810
W84	135,585	195	0	55
W91	31,953	7,546	0	0

1990, Period 2

BLDG_NO	PVT_LAV	M_LAV	F_LAV	TOTLAV
33	0	609	0	609
35	0	1,104	553	1,657
41	67	471	329	867
45	76	44	40	160
48	0	486	221	707
51	0	16	16	32
E10	30	488	495	1,013
E15	31	817	815	1,663
E17	179	735	758	1,672
E2	3,649	102	0	3,751
E20	66	59	0	125
E32	0	66	55	121
E40	0	723	632	1,355
E51	0	615	521	1,136
MC	8,591	21,908	17,846	48,345
N42	0	278	250	528
N51	0	661	463	1,124
N57	193	0	0	193
NW13	0	583	0	583
NW14	0	1,065	872	1,937
NW16	0	450	376	826
NW17	0	414	99	513
NW21	0	322	291	613
NW30	0	1,279	459	1,738
W11	0	30	30	60
W31	123	746	672	1,541
W45	0	0	0	0
W59	228	179	184	591
W61	6,045	261	201	6,507
W70	5,653	0	0	5,653
W71	1,745	158	656	2,559
W74	20	0	0	20
W84	0	57	0	57
W91	0	481	126	607

1990, Period 2

BLDG_NO	DUMDORM	USE	TYPE	GALSQFT
33	0	R	OTR	2.28
35	0	R	OTR	33.66
41	0	R	OTR	3.73
45	0	R	OTR	34.55
48	0	R	OTR	13.36
51	0	R	SRA	9.09
E10	0	MNS	OTR	8.66
E15	0	R	OTR	2.23
E17	0	R	OTR	36.25
E2	1	R	HSG	43.34
E20	0	R	OTR	5.23
E32	0	MNS	OTR	8.17
E40	0	R	OTR	16.72
E51	0	R	OTR	5.19
MC	0	GEN	MGL	28.92
N42	0	R	OTR	69.32
N51	0	RA	OTR	85.50
N57	0	R	OTR	0.28
NW13	0	R	OTR	2.02
NW14	0	R	OTR	66.54
NW16	0			0.00
NW17	0	R	OTR	1.68
NW21	0	R	OTR	16.80
NW30	0	R	OTR	0.45
W11	0	R	OTR	17.25
W31	0	R	SRA	47.04
W45	0	ANS	SRA	5.50
W59	0	R	OTR	5.10
W61	1	R	HSG	27.73
W70	1	MNS	HSG	33.00
W71	1	R	HSG	32.91
W74	0	R	OTR	103.25
W84	1	ANS	HSG	63.08
W91	0	R	OTR	52.04

1990, Period 2

BLDG_NO	GAL	H_DEG	C_DEG	PRECIP
33	100,500	3,390	128	22.25
35	2,021,250	3,390	128	22.25
41	127,500	3,390	128	22.25
45	426,750	3,390	128	22.25
48	580,500	3,390	128	22.25
51	48,750	3,390	128	22.25
E10	277,500	3,390	128	22.25
E15	234,750	3,390	128	22.25
E17	2,890,500	3,390	128	22.25
E2	3,114,750	3,390	128	22.25
E20	54,750	3,390	128	22.25
E32	100,500	3,390	128	22.25
E40	1,607,250	3,390	128	22.25
E51	260,250	3,390	128	22.25
MC	97,287,000	3,390	128	22.25
N42	2,065,500	3,390	128	22.25
N51	3,378,000	3,390	128	22.25
N57	12,750	3,390	128	22.25
NW13	115,500	3,390	128	22.25
NW14	8,979,750	3,390	128	22.25
NW16	0	0	0	0
NW17	67,500	3,390	128	22.25
NW21	1,305,750	3,390	128	22.25
NW30	37,500	3,390	128	22.25
W11	201,000	3,390	128	22.25
W31	2,940,000	3,390	128	22.25
W45	1,006,500	3,390	128	22.25
W59	165,000	3,390	128	22.25
W61	3,867,750	3,390	128	22.25
W70	3,300,000	3,390	128	22.25
W71	3,769,500	3,390	128	22.25
W74	136,500	3,390	128	22.25
W84	8,552,250	3,390	128	22.25
W91	1,662,750	3,390	128	22.25

1990, Period 2

BLDG_NO	KWH	NO_LASER	BLDG_AGE	PCTOFF
33	0	3	67.3	33.06
35	0	7	43.9	36.73
41	0	2	79.6	17.10
45	380,320	0	17.5	34.46
48	0	6	45.5	21.76
51	0	0	58.5	8.34
E10	431,385	1	81.6	30.68
E15	1,196,352	21	12.5	30.28
E17	2,710,410	0	30.5	15.04
E2	130,080	0	81.1	6.37
E20	405	1	74.5	10.30
E32	0	0	71.5	69.58
E40	0	0	25.5	59.77
E51	0	0	50.5	29.00
MC	20,477,154	629	51.2	21.17
N42	155,280	0	87.6	17.20
N51	390,720	0	70.5	13.67
N57	90,400	0	30.5	3.11
NW13	587,704	6	81.6	13.11
NW14	3,437,543	39	32.6	21.41
NW16	353,760	4	11.1	38.03
NW17	419,580	7	90.6	35.30
NW21	1,176,240	18	14.2	9.49
NW30	85,033	1	90.6	0.46
W11	31,080	1	27.5	13.79
W31	0	0	90.6	12.70
W45	127,593	0	90.6	0.18
W59	62,760	0	15.5	18.85
W61	0	0	26.0	8.79
W70	0	0	20.1	0.34
W71	0	0	14.8	0.65
W74	26,453	0	17.8	4.08
W84	0	0	23.7	0.14
W91	0	0	47.5	23.62

1990, Period 2

BLDG_NO	PCTCLS	PCTLAB	PCTLAV	BLD_TYPE
33	6.44	21.90	1.38	2
35	1.26	27.48	2.76	2
41	0.00	39.05	2.54	2
45	0.00	32.86	1.30	2
48	6.22	40.55	1.63	2
51	17.14	0.00	0.60	
E10	2.23	22.65	3.16	2
E15	2.55	19.32	1.58	2
E17	0.00	47.22	2.10	2
E2	0.00	0.99	5.22	1
E20	0.00	23.36	1.19	2
E32	2.76	0.00	0.98	3
E40	0.00	0.00	1.41	3
E51	28.63	0.00	2.26	3
MC	3.69	20.53	1.44	2
N42	0.00	10.47	1.77	2
N51	0.00	28.91	2.84	2
N57	0.00	0.00	0.43	2
NW13	0.00	47.67	1.02	2
NW14	0.80	50.90	1.44	2
NW16	0.00	4.92	1.77	3
NW17	0.02	23.58	1.27	2
NW21	0.00	57.94	0.79	2
NW30	0.00	0.00	2.07	2
W11	0.00	51.07	0.51	2
W31	0.20	0.00	2.47	2
W45	0.00	0.00	0.00	2
W59	0.00	1.01	1.83	2
W61	0.00	0.31	4.67	1
W70	0.00	0.00	5.65	1
W71	0.00	0.00	2.23	1
W74	0.00	61.27	1.51	2
W84	0.00	0.04	0.04	1
W91	0.00	0.00	1.90	3

Perl Scripts for Parsing Property Office Records

```
#!/afs/athena/contrib/perl/p

# aggreg.prl -- puts monthly electrical data into quarterly form

if ($#ARGV < $[) {
print "Usage: laser_parse.prl fname\n";
exit;
}

open(F, "$ARGV[0]") || die "cannot open $ARGV[0]: $!";

# Initialize arrays and variables.

@line = ();
@prev = ();
@out = ();
$qtr = 0;
$qtr_tot = 0;
$prv_qtr = 0;
$cur_qtr = 0;

# Read through the file

while (<F>) {

chop;

# Put every line into an array in order to get at fields, using the
```

```
# , as the field delimiter.

@line = split(/,/);

# If building number changes, write out the totals
&writeit if ($line[0] != $prev[0]);

# If meter number changes, write out the totals
&writeit if ($line[1] != $prev[1]);

# If year changes, write out totals
&writeit if ($line[4] != $prev[4]);

# If quarter changes, write out totals
&check_qtr;
&writeit if ($cur_qtr != $prv_qtr);

# Otherwise, accumulate total usage
$qtr_tot += $line[6];

# Here's where current quarter information is checked
sub check_qtr {
if ($line[5] == 1 || $line[5] == 2 || $line[5] == 3) {
$cur_qtr = 3;
}
if ($line[5] == 4 || $line[5] == 5 || $line[5] == 6) {
$cur_qtr = 4;
}
if ($line[5] == 7 || $line[5] == 8 || $line[5] == 9) {
$cur_qtr = 1;
```

```
}
if ($line[5] == 10 || $line[5] == 11 || $line[5] == 12) {
$cur_qtr = 2;
}
}

# Here's where totals get written
sub writeit {
$out[0] = $prev[0];
$out[1] = $prev[1];
$out[2] = $prev[2];
$out[3] = $prev[3];
$out[4] = $prev[4];
$out[5] = $prv_qtr;
$out[6] = $qtr_tot;
$qtr_tot = 0;

print "$out[0],$out[1],$out[2],$out[3],$out[4],
$out[5],$out[6]\n";

&loadprev;
}

# Here's where @prev gets loaded
sub loadprev {
$prev[0] = $line[0];
$prev[1] = $line[1];
$prev[2] = $line[2];
$prev[3] = $line[3];
$prev[4] = $line[4];
```

```
&check_qtr;
$prv_qtr = $cur_qtr;
}
}

&writeit;
```

```
#!/afs/athena/contrib/perl/p

# countem.prl -- calculates total electrical consumption in selected
# files



if ($#ARGV < $[) {
print "Usage: laser_parse.prl fname\n";
exit;
}

open(F, "$ARGV[0]") || die "cannot open $ARGV[0]: $!";

# Initialize arrays and variables
$kwh_tot = 0;

# Read through the file

while (<F>) {

chop;

# Put every line into an array in order to get at fields, using the
# , as the field delimiter.

@line = split(/,/);

$kwh_tot += $line[6];
}
```

```
print "$kwh_tot\n";
```

```
#!/afs/athena/contrib/perl/p

# laser_parse.prl -- puts a file of info about lasers on the MIT
# campus in comma-separated format.


if ($#ARGV < $[) {
print "Usage: laser_parse.prl fname\n";
exit;
}

open(F, "$ARGV[0]") || die "cannot open $ARGV[0]: $!";

# Initialize arrays and variables.

@line = ();
@out = ();
$i = 0;
$s = '"';

# Read through the file

while (<F>) {

chop;
tr/a-z/A-Z/;

# Put every line into an array in order to get at fields, using the
# | as the field delimiter.
```

```
if (/^\|/) {
@line = split(/\|/);
for ($i = 1; $i <= 6; $i++) {
$out[$i] = $line[$i];
}
}
else {
@line = split(/\|/);
for ($i = 1; $i <= 3; $i++) {
$out[$i+6] = $line[$i];
}
print "$s$out[1]$s,$s$out[2]$s,\
$s$out[3]$s,$s$out[4]$s,$s$out[5]$s,\
$s$out[6]$s,$s$out[7]$s,$s$out[8]$s,\
$s$out[9]$s\n";
}
}
```

```
#!/afs/athena/contrib/perl/p

# disposed.prl -- finds out the number and types of laser disposal


if ($#ARGV < $[) {
print "Usage: disposed.prl fname\n";
exit;
}

open(F, "$ARGV[0]") || die "cannot open $ARGV[0]: $!";

# Initialize arrays and variables
@type = ();
@count = ();

# Read through the file

while (<F>) {

chop;

# Put every line into an array in order to get at fields, using the
# , as the field delimiter.

@line = split(/,/);

if ($line[7] ne '""') {
$hit = 0;
$i = 0;
```

```
while ($i <= $k) {
if ($line[7] eq $type[$i]) {
$count[$i] += 1;
$hit = 1;
}
}
if ($hit == 0) {
$type[$k] = $line[7];
$count[$k] += 1;
$k++;
}
}
}
for ($i = 0; $i <= $k; $i++) {
print "$type[$i]\t$count[$i]\n";
}
```

```
#!/afs/athena/contrib/perl/p

# print_disp.prl -- prints contents of last two fields in lasers file


if ($#ARGV < $[) {
print "Usage: print_disp.prl fname\n";
exit;
}

open(F, "$ARGV[0]") || die "cannot open $ARGV[0]: $!";

# Initialize arrays and variables.

# Read through the file

while (<F>) {

chop;

# Put every line into an array in order to get at fields, using the
# , as the field delimiter.

@line = split(/,/);

# Just print out last two elements of this array

print "$line[7],$line[8]\n";
}
```

```
#!/afs/athena/contrib/perl/p

# quotes.prl -- surrounds numbers with quotation marks


if ($#ARGV < $[) {
print "Usage: laser_parse.prl fname\n";
exit;
}

open(F, "$ARGV[0]") || die "cannot open $ARGV[0]: $!";

# Initialize arrays and variables.
$q = '"';
@line = ();
@out = ();

# Read through the file

while (<F>) {

chop;

# Put every line into an array in order to get at fields, using the
# , as the field delimiter.

@line = split(/,/);

# Take each field and enclose it in double-quotes, then print it.
print "$q$line[0]$q,$q$line[1]$q\n";
```

```
}
```

```
#!/afs/athena/contrib/perl/p

# count_las.prl -- totals current lasers by building


if ($#ARGV < $[) {
print "Usage: count_las.prl fname\n";
exit;
}

open(F, "$ARGV[0]") || die "cannot open $ARGV[0]: $!";

# Initialize arrays and variables.

@line = ();
@prev = ();
@out = ();
$las_tot = 0;
$inner_tot = 0;
$tot = 0;

# Read through the file

while (<F>) {

chop;

# Put every line into an array in order to get at fields, using the
# , as the field delimiter.
```

```
@line = split(/,/);

# If the disposed of field is empty,

if ($line[7] eq '""') {

# If building number changes, write out the totals
&writeit if ($line[1] ne $prev[1]);

# Otherwise, accumulate total usage
$las_tot += 1;
$inner_tot += 1;

}

# Here's where totals get written
sub writeit {
$out[0] = $prev[1];
$out[1] = $las_tot;
$tot += $las_tot;
print "$out[0]\t$out[1]\n";
@out = ();

&loadprev;
}

# Here's where @prev gets loaded
sub loadprev {
$prev[0] = $line[0];
$prev[1] = $line[1];
```

```
$las_tot = 0;
}

}

&writeit;
print "Total number of lasers currently on campus equals $tot\n";
print "Check inner total equals $inner_tot\n";
```

```
#!/afs/athena/contrib/perl/p

# lasmtx.prl -- creates a matrix of the total number of lasers in a
# building at MIT by year and quarter.

if ($#ARGV < $[) {
print "Usage: lasmtx.prl fname\n";
exit;
}

open(F, "$ARGV[0]") || die "cannot open $ARGV[0]: $!";

# Initialize arrays and variables.
@prev = ();
@line = ();
@out = ();
$acq_mm = 0;
$acq_yy = 0;
$acq_qtr = 0;
$disp_mm = 0;
$disp_yy = 0;
$disp_qtr = 0;
$max_yy = 0;
$min_yy = 99;
$max_qtr = 0;
$min_qtr = 5;

# Initialize the counter arrays.

for ($i = 50; $i <= 99; $i++) {
```

```
for ($j = 1; $j <= 4; $j++) {
$bucket{$i,$j} = 0;
}
}


# Read through the file

while (<F>) {

# Isolate the fields.
chop;
@line = split(/,/);

# When the building number changes, write out a bunch of records.
if ($line[1] ne $prev[1]) {
if ($prev[1] ne "") {
&WRITEM_COWBOY;
&INITEM_COWBOY;
}
else {
$prev[1] = $line[1];
}
}

# For each laser, find out the acquisition month and year.
$acq_mm = substr($line[6],0,2);
$acq_yy = substr($line[6],4,2);

# Determine the quarter in which the laser was acquired.
```

```
$acq_qtr = &FIND_QTR($acq_mm);

# If the date gives the first or second quarter, decrement the year to
# reflect the fiscal year accurately.
if ($acq_qtr == 1 || $acq_qtr == 2) {
$acq_yy--;
}

# Find out the disposition month and year.
if ($line[8] ne '"') {
$disp_mm = substr($line[8],0,2);
$disp_yy = substr($line[8],4,2);

# Determine the quarter in which MIT rid itself of the laser.
$disp_qtr = &FIND_QTR($disp_mm);
}
else {
$disp_mm = 0;
$disp_qtr = 3;
$disp_yy = 92;
}

# If the date falls in the first or second quarter, decrement the
# year to reflect the fiscal year accurately.
if ($disp_qtr == 1 || $disp_qtr == 2) {
   $disp_yy--;
}

# Find the lowest values for acquisition year & acquisition month,
# then the highest values for disposition year & disposition month.
```

```
if ($min_yy >= $acq_yy) {
$min_yy = $acq_yy;
if ($min_qtr > $disp_qtr) {
$min_qtr = $acq_qtr;
}
}
if ($max_yy <= $disp_yy) {
$max_yy = $disp_yy;
if ($max_qtr < $disp_qtr) {
$max_qtr = $disp_qtr;
}
}

# For each quarter between the acquisition date and the disposition
# date, add to the appropriate quarter bucket for the building.

for ($i = $acq_yy; $i <= $disp_yy; $i++) {
if ($i == $acq_yy) {
for ($j = $acq_qtr; $j <= 4; $j++) {
$bucket{$i,$j} += 1;
}
}
elsif ($i == $disp_yy) {
for ($j = 1; $j <= $disp_qtr; $j++) {
$bucket{$i,$j} += 1;
}
}
else {
for ($j = 1; $j <= 4; $j++) {
```

```
$bucket{$i,$j} += 1;
}
}
}

# This subroutine keeps track of previous building numbers and
# initializes minimum and maximum variables.

sub INITEM_COWBOY {

# Clear out the array buckets.

for ($i = $min_yy; $i <= $max_yy; $i++) {
for ($j = 1; $j <= 4; $j++) {
$bucket{$i,$j} = 0;
}
}

# Initialize the variables.

$max_yy = 0;
$min_yy = 99;
$max_qtr = 0;
$min_qtr = 5;
$prev[1] = $line[1];

}

# This subroutine writes out the records for the number of lasers in a
```

```
# building by quarter.

 sub WRITEM_COWBOY             {

# Load up the building number.
 $out[2] = $prev[1];

# Load up year, quarter, and laser count.
 for ($i = $min_yy; $i <= $max_yy; $i++) {
 $out[0] = $i;
 if ($i == $min_yy) {
 for ($j = $min_qtr; $j <= 4; $j++) {
 $out[1] = $j;
 $out[3] = $bucket{$i,$j};
 &PRINTEM;
 }
 }
 elsif ($i == $max_yy) {
 for ($j = 1; $j <= $max_qtr; $j++) {
 $out[1] = $j;
 $out[3] = $bucket{$i,$j};
 &PRINTEM;
 }
 }
 else {
 for ($j = 1; $j <= 4; $j++) {
 $out[1] = $j;
 $out[3] = $bucket{$i,$j};
 &PRINTEM;
 }
```

```
}
}

# This subroutine prints out year, quarter, building number, and
# number of lasers.

sub PRINTEM {

print "$out[0],$out[1],$out[2],$out[3]\n";

}

}
# This subroutine finds the right quarter for the given month.
sub FIND_QTR {

local($qtr);
local($mon) = pop(@_);

if ($mon == 1 || $mon == 2 || $mon == 3) {
$qtr = 3;
}
if ($mon == 4 || $mon == 5 || $mon == 6) {
$qtr = 4;
}
if ($mon == 7 || $mon == 8 || $mon == 9) {
$qtr = 1;
}
if ($mon == 10 || $mon == 11 || $mon == 12) {
$qtr = 2;
```

```
}
$qtr;

}
}

# Write out the records for the last building.
&WRITEM_COWBOY;
```

```
#!/afs/athena/contrib/perl/p

# fmt_date.prl -- puts dates in laser data base into MDY format.

if ($#ARGV < $[) {
print "Usage: fmt_date.prl fname\n";
exit;
}

open(F, "$ARGV[0]") || die "cannot open $ARGV[0]: $!";

# Initialize arrays and variables.

@line = ();
@out = ();
$year = 0;
$month = 0;
$mon = 0;
$day = 0;

# Read through the file

while (<F>) {

chop;

# Put the fields in an array

@line = split(/,/);
&fmt_6;
```

```
&fmt_8;
print "$line[0],$line[1],$line[2],$line[3],\
$line[4],$line[5],$out[6],$line[7],$out[8]\n";


# Format the acquisition date.

sub fmt_6 {
$day = substr($line[6],1,2);
$year = substr($line[6],10,2);
$month = substr($line[6],4,3);
if ($month eq JAN) {
$mon = '01';
}
elsif ($month eq FEB) {
$mon = '02';
}
elsif ($month eq MAR) {
$mon = '03';
}
elsif ($month eq APR) {
$mon = '04';
}
elsif ($month eq MAY) {
$mon = '05';
}
elsif ($month eq JUN) {
$mon = '06';
}
elsif ($month eq JUL) {
```

```
$mon = '07';
}
elsif ($month eq AUG) {
$mon = '08';
}
elsif ($month eq SEP) {
$mon = '09';
}
elsif ($month eq OCT) {
$mon = '10';
}
elsif ($month eq NOV) {
$mon = '11';
}
else {
$mon = '12';
}

$out[6] = $mon.$day.$year;
}

# Format the disposition date
sub fmt_8 {
$day = substr($line[8],4,2);
$mon = substr($line[8],1,2);
$year = substr($line[8],7,2);

$out[8] = $mon.$day.$year;
}
}
```

Distributions for Percentage Changes in Building Space

Useable Space

	1982	1984	1986	1988	1990	1991
	===	===	===	===	===	===
X < -100%	0	0	0	0	0	0
-99.9% < X < -50.0%	2	2	0	1	0	0
-49.9% < X < -25.0%	4	0	0	0	0	0
-24.9% < X < -10.0%	9	2	0	0	8	0
-9.9% < X < -0.1%	28	25	35	28	78	18
= 0.0%	41	71	64	78	9	105
0.1% < X < 9.9%	56	35	39	34	41	17
10.0% < X < 24.9%	5	7	0	0	3	0
25.0% < X < 49.9%	2	2	1	0	0	0
50.0% < X < 99.9%	0	4	1	0	0	0
X > 100.0%	2	1	4	0	1	0

Office Space

	1982	1984	1986	1988	1990	1991
	===	===	===	===	===	===
X < -100%	0	0	0	1	0	1
-99.9% < X < -50.0%	3	3	2	2	1	0
-49.9% < X < -25.0%	3	4	0	6	4	1
-24.9% < X < -10.0%	2	8	5	9	10	0
-9.9% < X < -0.1%	26	16	22	22	31	10
= 0.0%	67	72	71	66	39	70
0.1% < X < 9.9%	33	26	31	27	35	35
10.0% < X < 24.9%	5	9	7	7	11	6
25.0% < X < 49.9%	5	5	3	2	6	4
50.0% < X < 99.9%	1	2	1	0	0	3
X > 100.0%	4	4	2	1	3	10

Class Space

	1982	1984	1986	1988	1990	1991
	===	===	===	===	===	===
< -100%	0	0	0	0	0	0
-99.9% < X < -50.0%	1	1	0	1	2	1
-49.9% < X < -25.0%	1	0	1	2	2	0
-24.9% < X < -10.0%	3	6	2	5	4	0
-9.9% < X < -0.1%	4	3	5	3	22	2
= 0.0%	121	130	125	126	100	134
0.1% < X < 9.9%	14	3	4	1	6	0
10.0% < X < 24.9%	2	2	5	2	2	2
25.0% < X < 49.9%	2	2	0	0	0	1
50.0% < X < 99.9%	0	1	0	1	0	0
X > 100.0%	1	1	2	0	2	0

Lab Space

	1982	1984	1986	1988	1990	1991
	===	===	===	===	===	===
< -100%	0	0	0	0	0	0
-99.9% < X < -50.0%	5	1	0	0	1	0
-49.9% < X < -25.0%	3	4	5	4	4	0
-24.9% < X < -10.0%	7	7	7	6	7	2
-9.9% < X < -0.1%	22	18	17	17	35	13
= 0.0%	84	95	87	90	65	117
0.1% < X < 9.9%	19	12	15	16	17	5
10.0% < X < 24.9%	6	6	6	4	5	2
25.0% < X < 49.9%	2	2	3	1	2	1
50.0% < X < 99.9%	0	1	2	1	0	0
X > 100.0%	1	3	2	2	4	0

Lavatory Space

	1982	1984	1986	1988	1990	1991
	===	===	===	===	===	===
< -100%	0	0	0	0	0	0
-99.9% < X < -50.0%	0	3	1	3	1	10
-49.9% < X < -25.0%	2	0	0	1	1	6
-24.9% < X < -10.0%	1	0	3	2	4	5
-9.9% < X < -0.1%	0	6	6	4	51	18
= 0.0%	121	127	115	128	47	99
0.1% < X < 9.9%	0	2	9	3	23	0
10.0% < X < 24.9%	0	3	3	0	7	0
25.0% < X < 49.9%	1	1	0	0	1	2
50.0% < X < 99.9%	2	2	0	0	4	0
X > 100.0%	22	5	7	0	1	0

Correlation Matrices Including Main Campus

1986, Period 1

Correlation	GAL	H_DEG	C_DEG	PRECIP	KWH	NO_LASER
GAL	1.000	NA	NA	0.000	0.994	0.995
H_DEG	NA	NA	NA	NA	NA	NA
C_DEG	NA	NA	NA	NA	NA	NA
PRECIP	0.000	NA	NA	NA	0.000	0.000
KWH	0.994	NA	NA	0.000	1.000	0.995
NO_LASER	0.995	NA	NA	0.000	0.995	1.000
BLDG_AGE	0.009	NA	NA	0.000	-0.011	0.012
PCTOFF	0.024	NA	NA	0.000	0.071	0.044
PCTCLS	0.028	NA	NA	0.000	0.021	0.046
PCTLAB	0.039	NA	NA	0.000	0.070	0.080
PCTLAV	-0.009	NA	NA	0.000	-0.045	-0.059

1986, Period 1

Correlation	BLDG_AGE	PCTOFF	PCTCLS	PCTLAB	PCTLAV
GAL	0.009	0.024	0.028	0.039	-0.009
H_DEG	NA	NA	NA	NA	NA
C_DEG	NA	NA	NA	NA	NA
PRECIP	0.000	0.000	0.000	0.000	0.000
KWH	-0.011	0.071	0.021	0.070	-0.045
NO_LASER	0.012	0.044	0.046	0.080	-0.059
BLDG_AGE	1.000	0.073	0.043	-0.108	-0.070
PCTOFF	0.073	1.000	0.071	-0.027	-0.152
PCTCLS	0.043	0.071	1.000	-0.179	-0.046
PCTLAB	-0.108	-0.027	-0.179	1.000	-0.279
PCTLAV	-0.070	-0.152	-0.046	-0.279	1.000

1987, Period 1

Correlation	GAL	H_DEG	C_DEG	PRECIP	KWH	NO_LASER
GAL	1.000	NA	NA	0.000	0.997	0.995
H_DEG	NA	NA	NA	NA	NA	NA
C_DEG	NA	NA	NA	NA	NA	NA
PRECIP	0.000	NA	NA	NA	0.000	0.000
KWH	0.997	NA	NA	0.000	1.000	0.997
NO_LASER	0.995	NA	NA	0.000	0.997	1.000
BLDG_AGE	-0.011	NA	NA	0.000	-0.022	0.002
PCTOFF	0.038	NA	NA	0.000	0.075	0.055
PCTCLS	0.027	NA	NA	0.000	0.026	0.045
PCTLAB	0.056	NA	NA	0.000	0.073	0.076
PCTLAV	-0.019	NA	NA	0.000	-0.044	-0.057

1987, Period 1

Correlations:	BLDG_AGE	PCTOFF	PCTCLS	PCTLAB	PCTLAV
GAL	-0.011	0.038	0.027	0.056	-0.019
H_DEG	NA	NA	NA	NA	NA
C_DEG	NA	NA	NA	NA	NA
PRECIP	0.000	0.000	0.000	0.000	0.000
KWH	-0.022	0.075	0.026	0.073	-0.044
NO_LASER	0.002	0.055	0.045	0.076	-0.057
BLDG_AGE	1.000	0.073	0.054	-0.109	-0.063
PCTOFF	0.073	1.000	0.114	0.025	-0.145
PCTCLS	0.054	0.114	1.000	-0.172	-0.041
PCTLAB	-0.109	0.025	-0.172	1.000	-0.269
PCTLAV	-0.063	-0.145	-0.041	-0.269	1.000

1987, Period 2

Correlation	GAL	H_DEG	C_DEG	PRECIP	KWH	NO_LASER
GAL	1.000	0.047	0.047	0.047	0.996	0.993
H_DEG	0.047	1.000	1.000	1.000	0.043	0.034
C_DEG	0.047	1.000	1.000	1.000	0.043	0.034
PRECIP	0.047	1.000	1.000	1.000	0.043	0.034
KWH	0.996	0.043	0.043	0.043	1.000	0.998
NO_LASER	0.993	0.034	0.034	0.034	0.998	1.000
BLDG_AGE	-0.013	-0.256	-0.256	-0.256	-0.011	0.011
PCTOFF	0.016	0.192	0.192	0.192	0.056	0.051
PCTCLS	0.028	0.072	0.072	0.072	0.030	0.047
PCTLAB	0.051	0.158	0.158	0.158	0.071	0.076
PCTLAV	-0.012	-0.047	-0.047	-0.047	-0.041	-0.057

1987, Period 2

Correlations:	BLDG_AGE	PCTOFF	PCTCLS	PCTLAB	PCTLAV
GAL	-0.013	0.016	0.028	0.051	-0.012
H_DEG	-0.256	0.192	0.072	0.158	-0.047
C_DEG	-0.256	0.192	0.072	0.158	-0.047
PRECIP	-0.256	0.192	0.072	0.158	-0.047
KWH	-0.011	0.056	0.030	0.071	-0.041
NO_LASER	0.011	0.051	0.047	0.076	-0.057
BLDG_AGE	1.000	0.073	0.049	-0.109	-0.067
PCTOFF	0.073	1.000	0.092	-0.002	-0.150
PCTCLS	0.049	0.092	1.000	-0.175	-0.043
PCTLAB	-0.109	-0.002	-0.175	1.000	-0.275
PCTLAV	-0.067	-0.150	-0.043	-0.275	1.000

1988, Period 1

Correlation	GAL	H_DEG	C_DEG	PRECIP	KWH	NO_LASER
GAL	1.000	0.048	0.048	0.048	0.996	0.993
H_DEG	0.048	1.000	1.000	1.000	0.044	0.034
C_DEG	0.048	1.000	1.000	1.000	0.044	0.034
PRECIP	0.048	1.000	1.000	1.000	0.044	0.034
KWH	0.996	0.044	0.044	0.044	1.000	0.996
NO_LASER	0.993	0.034	0.034	0.034	0.996	1.000
BLDG_AGE	-0.004	-0.256	-0.256	-0.256	-0.018	0.009
PCTOFF	0.039	0.204	0.204	0.204	0.090	0.063
PCTCLS	0.019	0.073	0.073	0.073	0.021	0.043
PCTLAB	0.042	0.159	0.159	0.159	0.063	0.075
PCTLAV	-0.025	-0.049	-0.049	-0.049	-0.042	-0.055

1988, Period 1

Correlations:	BLDG_AGE	PCTOFF	PCTCLS	PCTLAB	PCTLAV
GAL	-0.004	0.039	0.019	0.042	-0.025
H_DEG	-0.256	0.204	0.073	0.159	-0.049
C_DEG	-0.256	0.204	0.073	0.159	-0.049
PRECIP	-0.256	0.204	0.073	0.159	-0.049
KWH	-0.018	0.090	0.021	0.063	-0.042
NO_LASER	0.009	0.063	0.043	0.075	-0.055
BLDG_AGE	1.000	0.073	0.059	-0.108	-0.060
PCTOFF	0.073	1.000	0.136	0.056	-0.137
PCTCLS	0.059	0.136	1.000	-0.170	-0.038
PCTLAB	-0.108	0.056	-0.170	1.000	-0.262
PCTLAV	-0.060	-0.137	-0.038	-0.262	1.000

1988, Period 2

Correlation	GAL	H_DEG	C_DEG	PRECIP	KWH	NO_LASER
GAL	1.000	0.050	0.050	0.050	0.994	0.988
H_DEG	0.050	1.000	1.000	1.000	0.044	0.034
C_DEG	0.050	1.000	1.000	1.000	0.044	0.034
PRECIP	0.050	1.000	1.000	1.000	0.044	0.034
KWH	0.994	0.044	0.044	0.044	1.000	0.998
NO_LASER	0.988	0.034	0.034	0.034	0.998	1.000
BLDG_AGE	-0.021	-0.256	-0.256	-0.256	-0.009	0.010
PCTOFF	0.021	0.204	0.204	0.204	0.069	0.063
PCTCLS	0.015	0.073	0.073	0.073	0.027	0.044
PCTLAB	0.052	0.159	0.159	0.159	0.068	0.073
PCTLAV	-0.004	-0.049	-0.049	-0.049	-0.036	-0.054

1988, Period 2

Correlations:	BLDG_AGE	PCTOFF	PCTCLS	PCTLAB	PCTLAV
GAL	-0.021	0.021	0.015	0.052	-0.004
H_DEG	-0.256	0.204	0.073	0.159	-0.049
C_DEG	-0.256	0.204	0.073	0.159	-0.049
PRECIP	-0.256	0.204	0.073	0.159	-0.049
KWH	-0.009	0.069	0.027	0.068	-0.036
NO_LASER	0.010	0.063	0.044	0.073	-0.054
BLDG_AGE	1.000	0.073	0.059	-0.108	-0.060
PCTOFF	0.073	1.000	0.136	0.056	-0.137
PCTCLS	0.059	0.136	1.000	-0.170	-0.038
PCTLAB	-0.108	0.056	-0.170	1.000	-0.262
PCTLAV	-0.060	-0.137	-0.038	-0.262	1.000

1989, Period 1

Correlation	GAL	H_DEG	C_DEG	PRECIP	KWH	NO_LASER
GAL	1.000	0.070	0.070	0.070	0.993	0.991
H_DEG	0.070	1.000	1.000	1.000	0.056	0.049
C_DEG	0.070	1.000	1.000	1.000	0.056	0.049
PRECIP	0.070	1.000	1.000	1.000	0.056	0.049
KWH	0.993	0.056	0.056	0.056	1.000	0.996
NO_LASER	0.991	0.049	0.049	0.049	0.996	1.000
BLDG_AGE	0.001	-0.327	-0.327	-0.327	-0.016	0.010
PCTOFF	0.016	0.049	0.049	0.049	0.075	0.045
PCTCLS	0.020	0.048	0.048	0.048	0.026	0.047
PCTLAB	0.007	0.102	0.102	0.102	0.054	0.062
PCTLAV	-0.040	-0.108	-0.108	-0.108	-0.052	-0.061

1989, Period 1

Correlations:	BLDG_AGE	PCTOFF	PCTCLS	PCTLAB	PCTLAV
GAL	0.001	0.016	0.020	0.007	-0.040
H_DEG	-0.327	0.049	0.048	0.102	-0.108
C_DEG	-0.327	0.049	0.048	0.102	-0.108
PRECIP	-0.327	0.049	0.048	0.102	-0.108
KWH	-0.016	0.075	0.026	0.054	-0.052
NO_LASER	0.010	0.045	0.047	0.062	-0.061
BLDG_AGE	1.000	0.012	0.060	-0.126	0.007
PCTOFF	0.012	1.000	0.130	0.007	-0.148
PCTCLS	0.060	0.130	1.000	-0.176	-0.055
PCTLAB	-0.126	0.007	-0.176	1.000	-0.243
PCTLAV	0.007	-0.148	-0.055	-0.243	1.000

1989, Period 2

Correlation	GAL	H_DEG	C_DEG	PRECIP	KWH	NO_LASER
GAL	1.000	0.085	0.085	0.085	0.994	0.990
H_DEG	0.085	1.000	1.000	1.000	0.065	0.058
C_DEG	0.085	1.000	1.000	1.000	0.065	0.058
PRECIP	0.085	1.000	1.000	1.000	0.065	0.058
KWH	0.994	0.065	0.065	0.065	1.000	0.998
NO_LASER	0.990	0.058	0.058	0.058	0.998	1.000
BLDG_AGE	-0.019	-0.131	-0.131	-0.131	-0.018	0.002
PCTOFF	0.006	-0.097	-0.097	-0.097	0.062	0.055
PCTCLS	0.020	0.063	0.063	0.063	0.029	0.046
PCTLAB	0.031	0.165	0.165	0.165	0.065	0.067
PCTLAV	-0.020	-0.059	-0.059	-0.059	-0.045	-0.058

1989, Period 2

Correlations:	BLDG_AGE	PCTOFF	PCTCLS	PCTLAB	PCTLAV
GAL	-0.019	0.006	0.020	0.031	-0.020
H_DEG	-0.131	-0.097	0.063	0.165	-0.059
C_DEG	-0.131	-0.097	0.063	0.165	-0.059
PRECIP	-0.131	-0.097	0.063	0.165	-0.059
KWH	-0.018	0.062	0.029	0.065	-0.045
NO_LASER	0.002	0.055	0.046	0.067	-0.058
BLDG_AGE	1.000	0.041	0.059	-0.118	-0.027
PCTOFF	0.041	1.000	0.130	0.035	-0.143
PCTCLS	0.059	0.130	1.000	-0.173	-0.045
PCTLAB	-0.118	0.035	-0.173	1.000	-0.260
PCTLAV	-0.027	-0.143	-0.045	-0.260	1.000

1990, Period 1

Correlation	GAL	H_DEG	C_DEG	PRECIP	KWH	NO_LASER
GAL	1.000	0.046	0.046	0.046	0.993	0.994
H_DEG	0.046	1.000	1.000	1.000	0.048	0.034
C_DEG	0.046	1.000	1.000	1.000	0.048	0.034
PRECIP	0.046	1.000	1.000	1.000	0.048	0.034
KWH	0.993	0.048	0.048	0.048	1.000	0.989
NO_LASER	0.994	0.034	0.034	0.034	0.989	1.000
BLDG_AGE	-0.012	-0.256	-0.256	-0.256	-0.036	-0.003
PCTOFF	0.012	0.200	0.200	0.200	0.046	0.028
PCTCLS	0.022	0.066	0.066	0.066	0.014	0.044
PCTLAB	0.007	0.161	0.161	0.161	0.055	0.049
PCTLAV	-0.043	-0.025	-0.025	-0.025	-0.063	-0.071

1990, Period 1

Correlations:	BLDG_AGE	PCTOFF	PCTCLS	PCTLAB	PCTLAV
GAL	-0.012	0.012	0.022	0.007	-0.043
H_DEG	-0.256	0.200	0.066	0.161	-0.025
C_DEG	-0.256	0.200	0.066	0.161	-0.025
PRECIP	-0.256	0.200	0.066	0.161	-0.025
KWH	-0.036	0.046	0.014	0.055	-0.063
NO_LASER	-0.003	0.028	0.044	0.049	-0.071
BLDG_AGE	1.000	-0.015	0.060	-0.133	0.043
PCTOFF	-0.015	1.000	0.135	-0.025	-0.150
PCTCLS	0.060	0.135	1.000	-0.181	-0.070
PCTLAB	-0.133	-0.025	-0.181	1.000	-0.210
PCTLAV	0.043	-0.150	-0.070	-0.210	1.000

Correlation Matrices Excluding Main Campus

1986, Period 1

Correlations:	GAL	H_DEG	C_DEG	PRECIP	KWH	NO_LASER
GAL	1.000	NA	NA	0.000	0.645	0.595
H_DEG	NA	NA	NA	NA	NA	NA
C_DEG	NA	NA	NA	NA	NA	NA
PRECIP	0.000	NA	NA	NA	0.000	0.000
KWH	0.645	NA	NA	0.000	1.000	0.624
NO_LASER	0.595	NA	NA	0.000	0.624	1.000
BLDG_AGE	-0.123	NA	NA	0.000	-0.274	-0.152
PCTOFF	-0.127	NA	NA	0.000	0.231	0.038
PCTCLS	-0.199	NA	NA	0.000	-0.237	-0.081
PCTLAB	-0.051	NA	NA	0.000	0.181	0.397
PCTLAV	0.281	NA	NA	0.000	-0.006	-0.168

1986, Period 1

Correlations:	BLDG_AGE	PCTOFF	PCTCLS	PCTLAB	PCTLAV
GAL	-0.123	-0.127	-0.199	-0.051	0.281
H_DEG	NA	NA	NA	NA	NA
C_DEG	NA	NA	NA	NA	NA
PRECIP	0.000	0.000	0.000	0.000	0.000
KWH	-0.274	0.231	-0.237	0.181	-0.006
NO_LASER	-0.152	0.038	-0.081	0.397	-0.168
BLDG_AGE	1.000	0.072	0.042	-0.110	-0.069
PCTOFF	0.072	1.000	0.069	-0.029	-0.151
PCTCLS	0.042	0.069	1.000	-0.182	-0.044
PCTLAB	-0.110	-0.029	-0.182	1.000	-0.278
PCTLAV	-0.069	-0.151	-0.044	-0.278	1.000

1987, Period 1

Correlations:	GAL	H_DEG	C_DEG	PRECIP	KWH	NO_LASER
GAL	1.000	NA	NA	0.000	0.821	0.540
H_DEG	NA	NA	NA	NA	NA	NA
C_DEG	NA	NA	NA	NA	NA	NA
PRECIP	0.000	NA	NA	NA	0.000	0.000
KWH	0.821	NA	NA	0.000	1.000	0.782
NO_LASER	0.540	NA	NA	0.000	0.782	1.000
BLDG_AGE	-0.241	NA	NA	0.000	-0.321	-0.187
PCTOFF	-0.083	NA	NA	0.000	0.219	0.084
PCTCLS	-0.195	NA	NA	0.000	-0.200	-0.074
PCTLAB	0.113	NA	NA	0.000	0.249	0.409
PCTLAV	0.196	NA	NA	0.000	-0.010	-0.174
PCTLAV	-0.012	-0.047	-0.047	-0.047	-0.041	-0.057

1987, Period 1

Correlations:	BLDG_AGE	PCTOFF	PCTCLS	PCTLAB	PCTLAV
GAL	-0.241	-0.083	-0.195	0.113	0.196
H_DEG	NA	NA	NA	NA	NA
C_DEG	NA	NA	NA	NA	NA
PRECIP	0.000	0.000	0.000	0.000	0.000
KWH	-0.321	0.219	-0.200	0.249	-0.010
NO_LASER	-0.187	0.084	-0.074	0.409	-0.174
BLDG_AGE	1.000	0.072	0.053	-0.110	-0.062
PCTOFF	0.072	1.000	0.112	0.023	-0.143
PCTCLS	0.053	0.112	1.000	-0.175	-0.039
PCTLAB	-0.110	0.023	-0.175	1.000	-0.268
PCTLAV	-0.062	-0.143	-0.039	-0.268	1.000
PCTLAV	-0.067	-0.150	-0.043	-0.275	1.000

1987, Period 2

Correlations:	GAL	H_DEG	C_DEG	PRECIP	KWH	NO_LASER
GAL	1.000	0.137	0.137	0.137	0.671	0.356
H_DEG	0.137	1.000	1.000	1.000	0.115	0.051
C_DEG	0.137	1.000	1.000	1.000	0.115	0.051
PRECIP	0.137	1.000	1.000	1.000	0.115	0.051
KWH	0.671	0.115	0.115	0.115	1.000	0.792
NO_LASER	0.356	0.051	0.051	0.051	0.792	1.000
BLDG_AGE	-0.322	-0.257	-0.257	-0.257	-0.312	-0.191
PCTOFF	-0.238	0.191	0.191	0.191	0.105	0.090
PCTCLS	-0.200	0.071	0.071	0.071	-0.193	-0.065
PCTLAB	0.058	0.157	0.157	0.157	0.241	0.417
PCTLAV	0.264	-0.046	-0.046	-0.046	0.026	-0.171

1987, Period 2

Correlations:	BLDG_AGE	PCTOFF	PCTCLS	PCTLAB	PCTLAV
GAL	-0.322	-0.238	-0.200	0.058	0.264
H_DEG	-0.257	0.191	0.071	0.157	-0.046
C_DEG	-0.257	0.191	0.071	0.157	-0.046
PRECIP	-0.257	0.191	0.071	0.157	-0.046
KWH	-0.312	0.105	-0.193	0.241	0.026
NO_LASER	-0.191	0.090	-0.065	0.417	-0.171
BLDG_AGE	1.000	0.072	0.047	-0.110	-0.066
PCTOFF	0.072	1.000	0.090	-0.004	-0.148
PCTCLS	0.047	0.090	1.000	-0.178	-0.041
PCTLAB	-0.110	-0.004	-0.178	1.000	-0.273
PCTLAV	-0.066	-0.148	-0.041	-0.273	1.000

1988, Period 1

Correlations:	GAL	H_DEG	C_DEG	PRECIP	KWH	NO_LASER
GAL	1.000	0.147	0.147	0.147	0.720	0.384
H_DEG	0.147	1.000	1.000	1.000	0.114	0.053
C_DEG	0.147	1.000	1.000	1.000	0.114	0.053
PRECIP	0.147	1.000	1.000	1.000	0.114	0.053
KWH	0.720	0.114	0.114	0.114	1.000	0.679
NO_LASER	0.384	0.053	0.053	0.053	0.679	1.000
BLDG_AGE	-0.242	-0.257	-0.257	-0.257	-0.342	-0.194
PCTOFF	-0.112	0.203	0.203	0.203	0.298	0.125
PCTCLS	-0.243	0.071	0.071	0.071	-0.218	-0.073
PCTLAB	0.006	0.158	0.158	0.158	0.174	0.414
PCTLAV	0.137	-0.048	-0.048	-0.048	-0.001	-0.162

1988, Period 1

Correlations:	BLDG_AGE	PCTOFF	PCTCLS	PCTLAB	PCTLAV
GAL	-0.242	-0.112	-0.243	0.006	0.137
H_DEG	-0.257	0.203	0.071	0.158	-0.048
C_DEG	-0.257	0.203	0.071	0.158	-0.048
PRECIP	-0.257	0.203	0.071	0.158	-0.048
KWH	-0.342	0.298	-0.218	0.174	-0.001
NO_LASER	-0.194	0.125	-0.073	0.414	-0.162
BLDG_AGE	1.000	0.071	0.058	-0.109	-0.059
PCTOFF	0.071	1.000	0.134	0.054	-0.135
PCTCLS	0.058	0.134	1.000	-0.172	-0.036
PCTLAB	-0.109	0.054	-0.172	1.000	-0.261
PCTLAV	-0.059	-0.135	-0.036	-0.261	1.000

1988, Period 2

Correlations:	GAL	H_DEG	C_DEG	PRECIP	KWH	NO_LASER
GAL	1.000	0.123	0.123	0.123	0.758	0.382
H_DEG	0.123	1.000	1.000	1.000	0.121	0.053
C_DEG	0.123	1.000	1.000	1.000	0.121	0.053
PRECIP	0.123	1.000	1.000	1.000	0.121	0.053
KWH	0.758	0.121	0.121	0.121	1.000	0.783
NO_LASER	0.382	0.053	0.053	0.053	0.783	1.000
BLDG_AGE	-0.277	-0.257	-0.257	-0.257	-0.299	-0.193
PCTOFF	-0.185	0.203	0.203	0.203	0.145	0.132
PCTCLS	-0.202	0.071	0.071	0.071	-0.190	-0.067
PCTLAB	0.069	0.158	0.158	0.158	0.241	0.406
PCTLAV	0.219	-0.048	-0.048	-0.048	0.046	-0.160

1988, Period 2

Correlations:	BLDG_AGE	PCTOFF	PCTCLS	PCTLAB	PCTLAV
GAL	-0.277	-0.185	-0.202	0.069	0.219
H_DEG	-0.257	0.203	0.071	0.158	-0.048
C_DEG	-0.257	0.203	0.071	0.158	-0.048
PRECIP	-0.257	0.203	0.071	0.158	-0.048
KWH	-0.299	0.145	-0.190	0.241	0.046
NO_LASER	-0.193	0.132	-0.067	0.406	-0.160
BLDG_AGE	1.000	0.071	0.058	-0.109	-0.059
PCTOFF	0.071	1.000	0.134	0.054	-0.135
PCTCLS	0.058	0.134	1.000	-0.172	-0.036
PCTLAB	-0.109	0.054	-0.172	1.000	-0.261
PCTLAV	-0.059	-0.135	-0.036	-0.261	1.000

1989, Period 1

Correlations:	GAL	H_DEG	C_DEG	PRECIP	KWH	NO_LASER
GAL	1.000	0.204	0.204	0.204	0.596	0.272
H_DEG	0.204	1.000	1.000	1.000	0.104	0.077
C_DEG	0.204	1.000	1.000	1.000	0.104	0.077
PRECIP	0.204	1.000	1.000	1.000	0.104	0.077
KWH	0.596	0.104	0.104	0.104	1.000	0.665
NO_LASER	0.272	0.077	0.077	0.077	0.665	1.000
BLDG_AGE	-0.179	-0.329	-0.329	-0.329	-0.334	-0.197
PCTOFF	-0.160	0.047	0.047	0.047	0.314	0.107
PCTCLS	-0.233	0.046	0.046	0.046	-0.209	-0.070
PCTLAB	-0.159	0.101	0.101	0.101	0.210	0.444
PCTLAV	0.071	-0.106	-0.106	-0.106	-0.021	-0.155

1989, Period 1

Correlations:	BLDG_AGE	PCTOFF	PCTCLS	PCTLAB	PCTLAV
GAL	-0.179	-0.160	-0.233	-0.159	0.071
H_DEG	-0.329	0.047	0.046	0.101	-0.106
C_DEG	-0.329	0.047	0.046	0.101	-0.106
PRECIP	-0.329	0.047	0.046	0.101	-0.106
KWH	-0.334	0.314	-0.209	0.210	-0.021
NO_LASER	-0.197	0.107	-0.070	0.444	-0.155
BLDG_AGE	1.000	0.011	0.059	-0.127	0.008
PCTOFF	0.011	1.000	0.128	0.006	-0.146
PCTCLS	0.059	0.128	1.000	-0.178	-0.053
PCTLAB	-0.127	0.006	-0.178	1.000	-0.242
PCTLAV	0.008	-0.146	-0.053	-0.242	1.000

1989, Period 2

Correlations:	GAL	H_DEG	C_DEG	PRECIP	KWH	NO_LASER
GAL	1.000	0.216	0.216	0.216	0.647	0.356
H_DEG	0.216	1.000	1.000	1.000	0.106	0.058
C_DEG	0.216	1.000	1.000	1.000	0.106	0.058
PRECIP	0.216	1.000	1.000	1.000	0.106	0.058
KWH	0.647	0.106	0.106	0.106	1.000	0.802
NO_LASER	0.356	0.058	0.058	0.058	0.802	1.000
BLDG_AGE	-0.240	-0.132	-0.132	-0.132	-0.321	-0.203
PCTOFF	-0.268	-0.099	-0.099	-0.099	0.154	0.124
PCTCLS	-0.204	0.060	0.060	0.060	-0.199	-0.059
PCTLAB	-0.027	0.163	0.163	0.163	0.277	0.430
PCTLAV	0.173	-0.057	-0.057	-0.057	0.007	-0.159

1989, Period 2

Correlations:	BLDG_AGE	PCTOFF	PCTCLS	PCTLAB	PCTLAV
GAL	-0.240	-0.268	-0.204	-0.027	0.173
H_DEG	-0.132	-0.099	0.060	0.163	-0.057
C_DEG	-0.132	-0.099	0.060	0.163	-0.057
PRECIP	-0.132	-0.099	0.060	0.163	-0.057
KWH	-0.321	0.154	-0.199	0.277	0.007
NO_LASER	-0.203	0.124	-0.059	0.430	-0.159
BLDG_AGE	1.000	0.040	0.059	-0.118	-0.027
PCTOFF	0.040	1.000	0.128	0.033	-0.141
PCTCLS	0.059	0.128	1.000	-0.175	-0.043
PCTLAB	-0.118	0.033	-0.175	1.000	-0.259
PCTLAV	-0.027	-0.141	-0.043	-0.259	1.000

1990, Period 1

Correlations:	GAL	H_DEG	C_DEG	PRECIP	KWH	NO_LASER
GAL	1.000	0.156	0.156	0.156	0.725	0.190
H_DEG	0.156	1.000	1.000	1.000	0.109	0.056
C_DEG	0.156	1.000	1.000	1.000	0.109	0.056
PRECIP	0.156	1.000	1.000	1.000	0.109	0.056
KWH	0.725	0.109	0.109	0.109	1.000	0.469
NO_LASER	0.190	0.056	0.056	0.056	0.469	1.000
BLDG_AGE	-0.236	-0.257	-0.257	-0.257	-0.295	-0.208
PCTOFF	-0.088	0.200	0.200	0.200	0.156	0.099
PCTCLS	-0.255	0.064	0.064	0.064	-0.207	-0.066
PCTLAB	-0.088	0.161	0.161	0.161	0.238	0.454
PCTLAV	0.167	-0.023	-0.023	-0.023	-0.023	-0.147

1990, Period 1

Correlations:	BLDG_AGE	PCTOFF	PCTCLS	PCTLAB	PCTLAV
GAL	-0.236	-0.088	-0.255	-0.088	0.167
H_DEG	-0.257	0.200	0.064	0.161	-0.023
C_DEG	-0.257	0.200	0.064	0.161	-0.023
PRECIP	-0.257	0.200	0.064	0.161	-0.023
KWH	-0.295	0.156	-0.207	0.238	-0.023
NO_LASER	-0.208	0.099	-0.066	0.454	-0.147
BLDG_AGE	1.000	-0.015	0.060	-0.134	0.044
PCTOFF	-0.015	1.000	0.134	-0.025	-0.149
PCTCLS	0.060	0.134	1.000	-0.182	-0.067
PCTLAB	-0.134	-0.025	-0.182	1.000	-0.210
PCTLAV	0.044	-0.149	-0.067	-0.210	1.000

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